

JPRS-JST-90-046

23 OCTOBER 1990



**FOREIGN  
BROADCAST  
INFORMATION  
SERVICE**

# ***JPRS Report***

## **Science & Technology**

---

***Japan***

SYMPOSIUM ON TRENDS IN ADVANCED MATERIALS

JPRS-JST-90-046  
23 OCTOBER 1990

SCIENCE & TECHNOLOGY  
JAPAN  
SYMPOSIUM ON TRENDS IN ADVANCED MATERIALS

90FE0316 Chiba PROCEEDINGS OF SYMPOSIUM ON TRENDS IN ADVANCED MATERIALS 27 Apr 90 pp 1-41

[Selected articles from the Proceedings of Symposium on Trends in Advanced Materials held 27 Apr 90 in Chiba, sponsored by the Science Council of Japan, the Ceramics Society of Japan]

CONTENTS

Current Status, Future Outlook for Diamond Thin Film [Yoichiro Satoh].....	1
Frontier of High Tc Superconducting Materials [Koichi Kitazawa].....	9
Expectation for Space Planes and Thermal Insulation, Thermal Resistance [Shigeo Kobayashi].....	17
Significance and Impact of Organic Non-Linear Optical Materials [Hachiro Nakanishi].....	30
Electronics Industry--Life After Its Maturity [Shojiro Asai].....	45

## Current Status, Future Outlook for Diamond Thin Film

90FE0316A Tokyo Science Council of Japan in Japanese 27 Apr 90 pp 1-6

[Article by Yoichiro Satoh, National Research Institute for Inorganic Materials]

[Text] The diamond has many potential uses in a wide area of applications. It is the hardest material and has the highest thermal conductivity among all materials. It also has a high electrical resistivity and high transmissivity with respect to a wide range of wavelengths from ultraviolet to infrared (excluding a part of infrared zone) regions. It is also chemically stable. In addition to these intrinsic material properties, the diamond can be made light absorptive as well as luminescent over a wide range of wavelengths by introducing impurities and/or defects. It also possesses the properties of a semiconductor. By combining these characteristics, it is possible to obtain unique functional capabilities which are not to be expected from other materials, and which have many applications in various advanced technologies. In spite of these possibilities, the current use of the diamond has been rather limited, mainly because of difficulties in synthesizing it to match the requirements for various forms, shapes, and sizes. Another difficulty is the lack of technology to control its impurities and faults.

The vapor phase method is a new synthesis method which is free from many constraints found in the traditional high pressure method. This method is also attracting attention as a basic crystal growth technology in the thermodynamically stable region.

As a synthesizing technology, the vapor phase equipment is simple, and it permits diamond crystal growth over various types of substrates. Theoretically, there is no limit to the size of crystals to be grown, and the method is suitable for impurity control. On the other hand, the vapor deposited diamond films obtained so far are polycrystalline films, and show some faults unique to the vapor phase method as compared to the natural or high pressure synthesized diamond crystals. These are the areas for which improvements are to be made for future applications.

In this paper, the current status on synthesis methods and the properties of vapor deposited diamond films will be discussed along with its future tasks and possible developmental areas.

## 1. Synthesis Method

Although there are several synthesis methods known today appearing to be greatly different from each other, they all share common characteristics. For example, the structure and the texture (morphology) of synthesized diamond films vary depending upon the synthesis condition, especially dependent strongly upon the vapor composition and substrate temperature. This indicates that the major processes involved in reaction mechanism are essentially identical.

### Equipment

"The Hot Filament Method,"<sup>1</sup> which was conceived during the early period (Figure 1), consists of a tungsten wire filament in the conventional thermal CVD system, and a substrate holding plate at the center of the reaction chamber. A coil shaped tungsten wire is placed from a few millimeters to 10 millimeters above this plate, and it is kept approximately at 2,000°C by electric current. Figure 2 depicts a plasma CVD system<sup>2</sup> using the microwave as the exciter. This microwave has a frequency 2450 MHz, and is guided to the reaction chamber made of quartz glass through a wave guide tube before it generates the plasma. The reaction is done normally under a vacuum of 20-100 Torr.

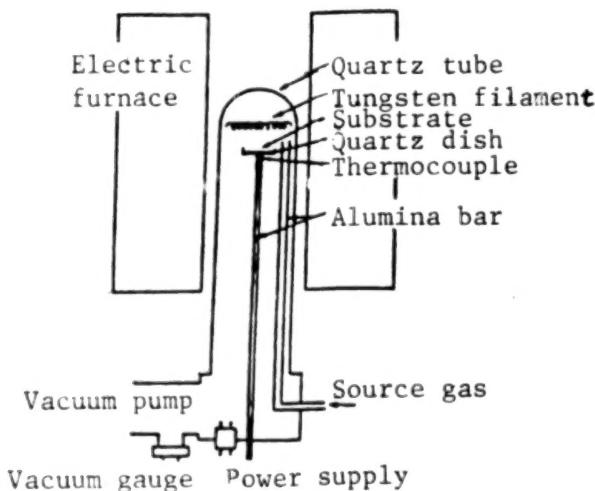


Figure 1. A Schematic of the "Hot Filament Method"<sup>1</sup>

The diamond synthesis can also be accomplished by a plasma CVD method using the high radio frequency wave of a frequency of 13.5 MHz or less under the same condition as that used in the microwave system.<sup>3</sup> In addition, there is a method in which a bias voltage is added between the anodic substrate and the cathodic filament.<sup>4</sup>

There is also a method using arc discharge plasma under a pressure of less than 1 atm. Two methods have been reported for the generation of arc discharge: one using high radio frequency waves, and the other using the direct current.<sup>5-7</sup> Figure 3 depicts a diamond synthesis system using high

frequency radio waves as the exciter. In this system, the energy density of plasma is high requiring the substrate to be cooled. One of the more unique aspects of the arc plasma method (thermal plasma method) is that it can attain the high speed film growth, which is reported to be as high as a few microns per minute.

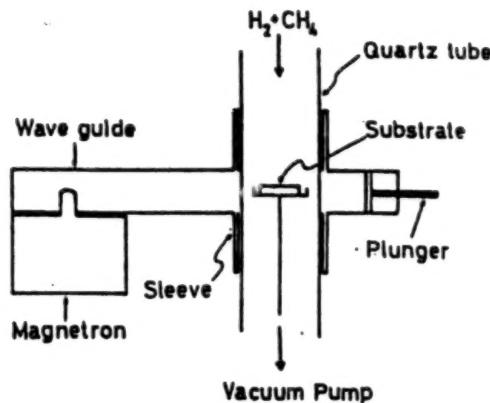


Figure 2. A Schematic of the "Microwave Plasma Method"<sup>2</sup>

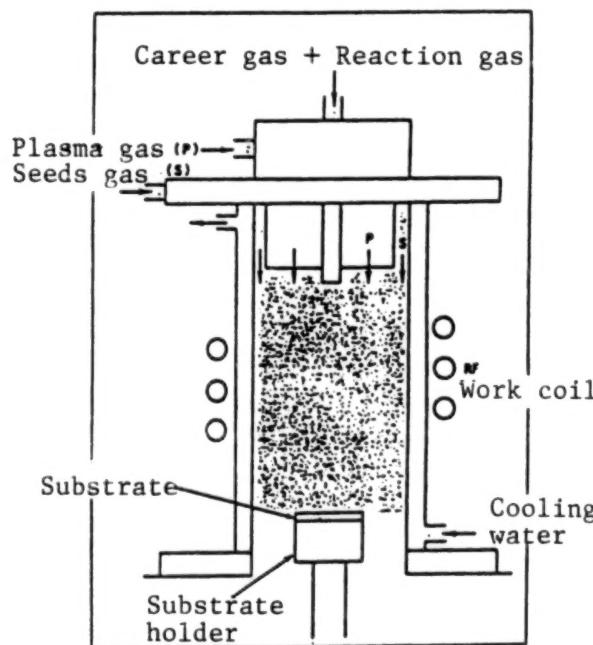


Figure 3. A Schematic of the "Radio Frequency Arc Plasma Method"<sup>5</sup>

One further new method is the "Combustion Flame Method."<sup>8</sup> As depicted in Figure 4, this method employs a burner using acetylene vapor mixed with oxygen to produce the atmospheric combustion. A pre-cooled substrate is placed in an appropriate position of the combustion flame, over which diamond film can grow. This is the simplest method.

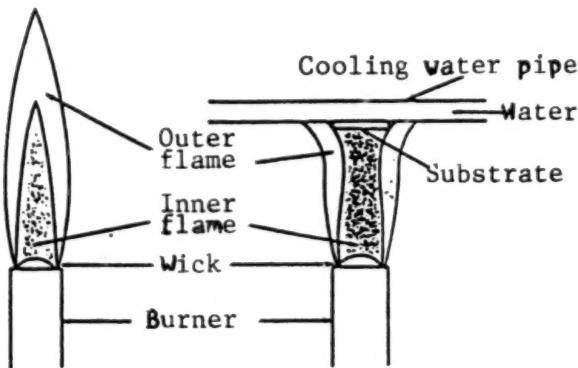


Figure 4. A Schematic of the Combustion Flame Method<sup>8</sup>

#### Source Gases

The typical gas mixture used in the diamond synthesis consists of methane and hydrogen together with various carbon-containing compounds as the carbon source. Hydrocarbon vapors such as ethane, butane, ethylene with double bonds, or acetylene with triple bonds, as well as ethanol, acetone and a mixture of carbon monoxide and hydrogen are used for the synthesis. There is a definite range suitable for the synthesis as far as the mixing ratio between the carbon source gas and hydrogen is concerned. If the concentration of the carbon source gas is too low, there will be no diamond precipitation. If, on the other hand, its concentration is too high, graphite will be precipitated. For oxygen-containing gases, the correct carbon concentration becomes higher as its oxygen concentration increases.

#### 2. Structure, Texture and Properties

Table 1 depicts the properties of diamond films which were synthesized under an optimum condition. Considering the fact that these are polycrystalline films, these properties are virtually identical to those of natural diamond. The lattice constant is approximately equal to that of natural diamond with a deviation of 0.2 percent.

As mentioned earlier, the diamond structure and texture are affected by the synthesis condition, especially by the vapor composition and the substrate temperature. These factors also affect the properties of the diamond. As an example, the effect of the variation in the source vapor composition upon the synthesized diamond will be discussed herein.

##### 2.1 Structure and Texture

The polycrystalline films shown here have been grown over a silicon substrate heated to a temperature of 840-860°C (microwave input power of approximately 400W) by using the microwave plasma CVD method, and with the mixture of methane and hydrogen (methane concentration 0.5-5 percent) as the carbon source. In order to increase the number of nucleation sites for the crystals, the substrate surface is treated with diamond powders.

Table 1. Basic Properties of Polycrystalline Diamond Films

	Polycrystalline film (vapor phase method)	Natural diamond (single crystal)
Lattice constant	$3.567 \pm 0.005 \text{ \AA}$	$3.5667 \text{ \AA}$
Hardness (Noop hardness)	Over 10,000 kg/mm <sup>2</sup>	12,000 kg/mm <sup>2</sup>
End of light absorption spectrum	225 nm	225 nm (Type II)
Resistivity	$10^9\text{-}10^{10} \text{ Ohm}\cdot\text{cm}$	$10^{13} \text{ Ohm}\cdot\text{cm}$
Thermal conductivity	1,000 W/K·m (100°C)	1,000 W/K·m (Type I Room Temp) 2,500 W/K·m (Type II Room Temp)

Figure 5 [not reproduced] depicts the SEM images of polycrystalline surfaces having the thickness of 30-40 microns, which were synthesized under different concentrations of methane. As the concentration of methane is varied from 0.5 percent to 5 percent, the surface crystal texture also undergoes distinct changes.

Including the surface produced by the 5 percent methane concentration, which shows no crystal boundaries, all films show the clear X-ray diffraction pattern of the diamond. In order to examine the surface having the double bond structure or that having amorphous characteristics similar to that of graphite (hereafter this surface structure will be called the "amorphous carbon"), the Raman spectrum was used as shown in Figure 6. In this figure, the Raman line for the diamond is depicted by a sharp peak at  $1333 \text{ cm}^{-1}$ . When the methane concentration is 0.5 percent and 2 percent, the wide Raman scatter having its peak around  $1500 \text{ cm}^{-1}$  can be seen indicating the presence of double bonds. When the methane concentration is 5 percent, additional Raman scatters are observed at  $1360 \text{ cm}^{-1}$  and  $1600 \text{ cm}^{-1}$  indicating the existence of amorphous carbon (the basic structure of amorphous carbon is graphite and its crystallinity is very small being similar to activated charcoal and carbon black).

## 2.2 Modulus of Elasticity and Thermal Conductivity

As mentioned above, the synthesized film structure and texture will vary with respect to the methane concentration. This variation also causes changes in material properties. As examples of these property changes, Figure 7 compares the changes in the modulus of elasticity<sup>10</sup> and thermal conductivity.<sup>9</sup> For both properties, the reference value of 100 is assigned at a low concentration of methane, and the relative changes with respect to the values at the reference concentration are depicted. Even considering the fact that these data are obtained with different specimens, the change in the thermal conductivity is large indicating a strong sensitivity to the structural change.

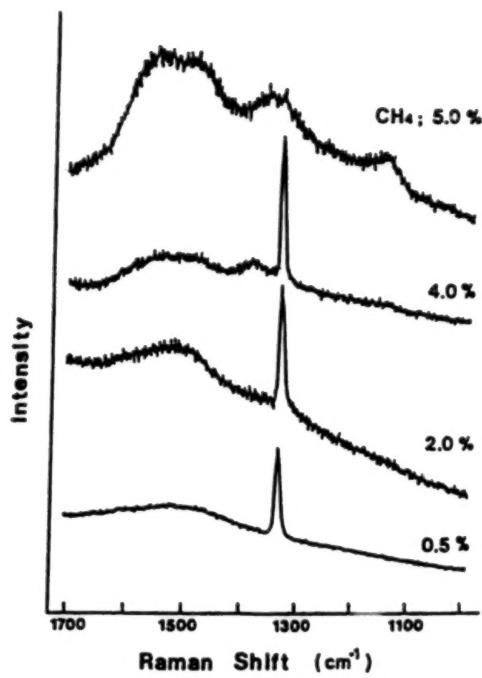


Figure 6. Raman Spectrum of Polycrystalline Film Grown Under Various Methane Concentration

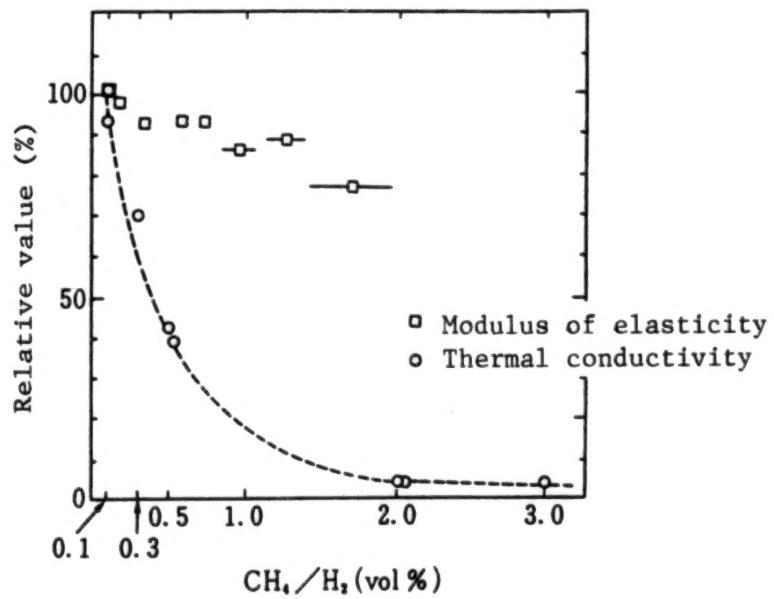


Figure 7. Comparison of Relative Change in Modulus of Elasticity and Thermal Conductivity for Polycrystalline Films Grown Under Various Methane Concentration<sup>9,10</sup>

### 2.3 Single Crystal and Polycrystalline Films

Recent research shows that the single crystal film synthesized under the identical condition has much smaller concentration faults and strains than the polycrystalline film.<sup>10</sup> This fact suggests that the measurements must be made for single crystal film, if one wants to obtain correct understanding of the characteristics of synthesized diamond films.

### 3. Future Tasks and Trends

There are many important diamond properties that are to be carefully observed, including mechanical, thermal, optical, electrical, and chemical properties depending upon the multitude of diamond applications. How is each of these properties affected by the faults or the impurities? More generally, how sensitive are these properties with respect to the diamond crystal structure? In this paper only the thermal conductivity and the modulus of elasticity are compared. Not only is the modulus of elasticity, but also other mechanical properties such as hardness and wear resistance are considered relatively insensitive to the faults. Although it has been shown that thermal conductivity has the higher structural sensitivity than the modulus of elasticity, the optical properties and the electrical properties are even more sensitive to the structure than thermal conductivity. These properties clearly require tougher controls of faults and impurities. Since the diamond has many variations, it is important to emphasize the structural sensitivity of its properties. In other words, its application should not be controlled by a single requirement, but should be controlled depending upon the desired property and the purpose of its applications.

To delineate the relationship between properties of the diamond and its faults and impurities is one of the important future tasks for the proper application of diamond film. This task is essentially the very basic research on the diamond as a material. It will not be too far in the future when the vapor deposition method to synthesize the diamond will be widely used for this research.

In addition to the basic problem of film growth mechanism, there are other important tasks regarding the control of nucleation sites (improvement of the nucleation site density), epitaxial growth, vapor phase nucleation sites (uniform nucleation), synthesis of n-type semiconductors having low electric resistivity, low temperature synthesis, etc.

### References

1. S. Matsumoto, Y. Sato, M. Kamo, and N. Setaka, Jpn. J. Appl. Phys., 21, L183 (1982).
2. M. Kamo, Y. Sato, S. Matsumoto, and N. Setaka, J. Cryst. Growth, 62, 642 (1983).
3. S. Matsumoto, J. Mater. Sci. Lett., 4, 600 (1985).

4. A. Sawabe and T. Inuzuka, Thin Solid Films, 137, 189 (1986).
5. S. Matsumoto, T. Kobayashi, M. Hino, T. Ishigaki, and Y. Moriyoshi, Pro. 8th Int. Conf. Plasma Chemistry, Tokyo, 1987, p 2458.
6. Matsumoto, New Diamond, Vol 4, No 1, 25 (1988).
7. Kawarada, Kurihara, Sasaki, Kosino, New Diamond, Vol 4, No 2, 30 (1988).
8. Y. Hirose and Y. Kondo, 34th Applied Physics Conference, Preprint Series No 2, p 434 (1987 Spring); Y. Hirose and M. Miizumi, New Diamond, Vol 4, No 3, 34 (1988).
9. A. Ono, T. Baba, H. Funamoto, and A. Nishikawa, Jpn. J. Appl. Phys., 25, L808 (1986).
10. Y. Sato and M. Kamo, Surface and Coatings Technology, 39/40, 183 (1989).

## Frontier of High Tc Superconducting Materials

90FE0316B Tokyo Science Council of Japan in Japanese 27 Apr 90 pp 7-16

[Article by Koichi Kitazawa, University of Tokyo, Faculty of Engineering]

### [Text] 1. Introduction

The emergence of high temperature superconductors can be summarized by the following three points as far as its impact is concerned.

First, it succeeded in resuscitating science fiction type dreams for us who have been engaged in material science research. The amount of fantasy stories pertaining to superconductivity compiled during the past 3 years has been enormous. The common task of scientists is to materialize these dreams through the development of technology. As a result of discussions around these fantasies, many young researchers started their careers in this field. The high temperature superconductor fantasies also triggered the launching and the advance of low temperature superconductor dreams. We have again begun to think about the possibility for restructuring the Japanese islands through the use of magnetically levitated trains in the beginning of the 21st century.

Second, the young researchers' notions of present-day science, "almost anything to be known has already been known," has been dispelled. In science, the deeper they explore, the more discouraged will become the young researchers. This is because young researchers begin to lose sight of the space in which their future activities can be projected. Simply because the "goddess" of the high temperature superconductor has not revealed the true nature of herself, many scientists are still enchanted by her. Scientists also find that there is a moat around the "goddess's" palace. This moat represents the task of understanding the electron images under the normal conductivity state which defies the traditional Band theory. Unless they can cross this moat, it is impossible for the researchers to get near the "goddess."

The third point is related to science and technology policy. The high temperature superconductors emerged when the economic friction among advanced nations developed into technology friction, which further backed up into research friction. This coincided with the time when Japanese companies

decided to become more internationally minded, and when a positive posture of Japan's willingness to make international contribution was pressed. Using this opportunity, Japan declared its new science and technology policy stipulating "Japan's international contribution to future technology" in order to impress the rest of the world. One of Japan's research organizations with the name of the "International Superconductivity Center" solicited international participation in its research activities even in THE WALL STREET JOURNAL. This is a historic development. On the other hand, however, the United States hinted that its superconductivity research will be kept confidential. This is symbolic of the changes that are taking place in the international science and technology scene.

During the past 3 years, the author has been in the midst of a large eddy current representing these three different points of view, and has been looking at the field of high temperature superconductivity from the stand-point of matter and materials. In this paper, the current state-of-the-art information on the first and second points mentioned above will be discussed.

## 2. On Superconducting Mechanism

Since the discovery of superconductivity in 1911, the mechanism of superconductivity has been considered the most difficult problem of 20th century solid state physics. Scientists have been working hard on this subject for over 40 years. The source of the difficulty is that it defies the Band theory, which can explain the semiconductor behavior by the behavior of a single electron. The essence of superconductivity is rooted into the concerted phenomena of a multitude of electrons. The multi-body theorem cannot be solved analytically. It has been said that Landau, one of the greatest scientists of the 20th century, was extremely angry when he was told that this superconductivity problem was finally solved by the BCS theory.

Our feeling toward the "goddess" of high temperature superconductivity is very similar to that of Landau. We are hoping that the "goddess" will remain forever mysterious. Yet at the same time, we have another feeling that we may have seen through the inside of the "goddess's" veil through the BCS theory. Fortunately or unfortunately, this veil has been found to be considerably opaque.

The BCS theory starts from the set of multitude of single electrons (this is called the Fermi fluid, and Landau et al. developed its concept), and can be expressed by the normal electron state of metal, namely by the Band theory. This electron system forms the Fermi surface, around which the mutual attraction takes place between every two pairs of electrons resulting in the formation of the Cooper pairs. This process necessitates phonons as the medium to cause the pairs of two electrons to fall into a more stable state, which results in a superconductive state.

### 2.1 Is the Band Mechanism Valid?

In other words, the BCS mechanism is based on studying how the metallic electron system in the Band state would go through its phase change. The

biggest controversy surrounding high temperature superconductivity is a suspicion that the electron system may not be in the Band state to begin with. If this suspicion is correct, the BCS theory would lose its foundation as the central figure in the theatrical stage of superconductivity debate. The current status is that researchers belonging to the Band school (Fermi fluid theory school) and to the non-Band school (non-Fermi fluid school) are arguing with each other on the interpretation of experimental results.

If the Band based concept is invalid, there should be another concept for the state of electron systems before it becomes superconductive. Since it is clear now that the BCS mechanism has been invalidated, we must look for a fundamentally different mechanism. This is the reason that many theorists and experimentalists are now suffering from a sort of scientific fever. When the Band theory collapsed, it left behind a chaos in the electron system. The uniqueness of this electron system is that electrons are moving around in such a manner that there are strong Coulomb repulsive forces among them preventing each one from interfering with the influence of other electrons. In accordance with the Band theory, many electrons could move around the space completely freely and independently from other electrons.

P. W. Anderson, a Nobel prize winner, is the first to point out that electron movement has the fundamental importance to superconductivity. Although his first suggestion was later rejected, its basic concept has been inherited and modified taking different forms by many theoreticians. Nevertheless, each of these models is still very rough in shape, and not in the state to be validated by the experimental data.

On the other hand, there are other efforts being made based on the Band theory, in which the theory is expanded to consider the strong inter-electron repulsive forces found in the copper oxide superconductors. If this approach is correct, the overall frame of the BCS theory is still valid. There are, however, many phenomena that defy the understanding in the area of optical properties and electromagnetic properties. The current status is that no one knows which approach is close to the truth.

The first task is to delineate the electron structure of the normal conducting mechanism before the mechanism of superconductivity is to be explored.

## 2.2 Phonon Mechanism, Charge Fluctuation and Spin Fluctuation

If the Band theory is valid, the problem will be the attractive force mechanism which serves as a media for the Cooper pairs in the general frame of the BCS theory. Although the BCS theory assumes the phonon as a media, this could also be accomplished by other excitation phenomena. Although, in the global classification, the BCS considers the electric charge fluctuation as an excitation phenomena based on the Coulomb type mutual reaction, it can accommodate the spin fluctuation which is the excitation phenomena based on the spins' mutual reaction.

In the phonon mechanism, the critical temperature can be changed without changing the electron system by simply changing the phonon frequency by substituting isotopes. In the high temperature superconductor, this effect was found to be very small making the phonon mechanism less predominant. Although, with this reason, the phonon mechanism theory has been currently set aside, there are other experimental results demonstrating the large interaction between phonons and electrons. This is the reason that premature decisions are not warranted. Research results to date show the deficiency in some models based on the spin fluctuation. Since high temperature superconductors go through the transition into the anti-ferromagnetic phase by a slight degree of composition change, the spin model is a strong candidate. As far as the electric charge fluctuation goes, there are other several models depending upon where the fluctuations occur. The spin model is still considered to be a powerful model, nevertheless.

In all of these cases, the general frame of BCS is still valid, indicating that there is virtually very little difference between the high temperature superconductivity and the conventional superconductivity. It appears from the research results to date that the electron pairs play a role in superconductivity, and that the general frame regarding the behavior of the critical magnetic field as well as the temperature dependency of the magnetic penetration has not been invalidated. A similar argument, however, may be made from the non-Band theory point of view, making it more difficult to derive a correct judgment. The judgment as to which is correct appears to be a very delicate matter.

### 2.3 Superconductivity by the Non-Fermi Fluid

If the extension of the Band theory fails to explain the electron dependency before superconductivity (above  $T_c$ ), another concept needs to be developed to explain the mechanism of superconductivity. This new concept must be able to express the electron motion by taking into account the strong inter-electron repulsive force and the mutual reaction of spins. The concept is, however, very primitive as compared to the Band theory, and is unable to explain the superconductive phenomena. Nevertheless this is completely different from the BCS mechanism. The new theory may be expected to have a potential pointing the way to develop higher  $T_c$  materials and new devices.

At this point in time, however, we have not seen any material having significantly different superconductive characteristics, except for the shape of superconductive gaps. I do not believe that we can produce superconductive materials which will be significantly different from those following the BCS mechanism.

## 3. Technological Frontiers

Interest in the temperature superconductivity is gradually increasing as evidenced by its recent applications in MRI and others. This "lift off" of the superconductivity market is due to its technological advances. As long as the present costs involved in producing the 4.2K cooling can drastically be decreased, the high temperature superconductors requiring liquid nitrogen

cooling will not be necessary. What is needed is the revolutionary technological innovation in cryogenic cooling. A closed cycle cooling system which does not consume He gas has already been developed for the magnetic levitation train.

If cooling to the level of 20K is good enough, the multi-stage machine would no longer be needed, making the cryogenic cooling much easier. It is also possible to use the high temperature superconductor at the 20K range with improved performance rather than at the liquid nitrogen temperature. The latter approach requires that the high temperature superconductor at 20K achieve the same level of performance as the low temperature superconductor at 4.2K. The best data currently are approaching this goal.

Although the use of the high temperature superconductor at around 77K would make refrigeration easier and thermal insulation simplified, the major concern currently is whether superconducting materials having the characteristics suitable for this application can be made or not. If the superconductor's material characteristics for such an application can be made to match those used in cryogenic applications, it will open up the new application of strong permanent magnets. This will constitute a basis for many new applications of light weight and strong magnets which have never been thought of before.

If room temperature superconductors are realized, the application range would further be increased, although such a prediction appears to be impossible.

### 3.1 Development of New Material

Currently there are three types of high temperature superconductors: the Y-system (the 123 system having  $T_c$  of 90K), the Bi-system (110K) and the Tl system (120K). A variety of possibilities are being explored, such as the development of new material system with a higher  $T_c$  or materials having improved performance at the current temperature levels. Among these three material systems, the Y-system has the least amount of heterogeneity and the highest critical current in the high magnetic field at 77K. Although the Bi-system shows a good performance at 20K or lower temperature level, the large current cannot be used in the strong magnetic field at 77K. Superconductive materials having large heterogeneity have the short coherence length in the direction normal to their layer like structures, reducing the continuity of superconductivity at the layer interface (weak bonding). This also weakens the pinning strength for magnetic flux lines. The most desirable new material should have low heterogeneity, which is difficult to find along the extrapolation of the current materials. New approaches different from the current method are needed, although it is difficult to make predictions on any new materials.

### 3.2 Critical Current

Figure 1 depicts the critical current data at 77K for high temperature superconductors with respect to the magnetic field. As far as the thin film and single crystal materials are concerned, the critical current at 77K for high temperature materials are getting closer to that of the conventional

superconductors at 4.2K. The real problem is whether this performance can be realized in practical material or not.

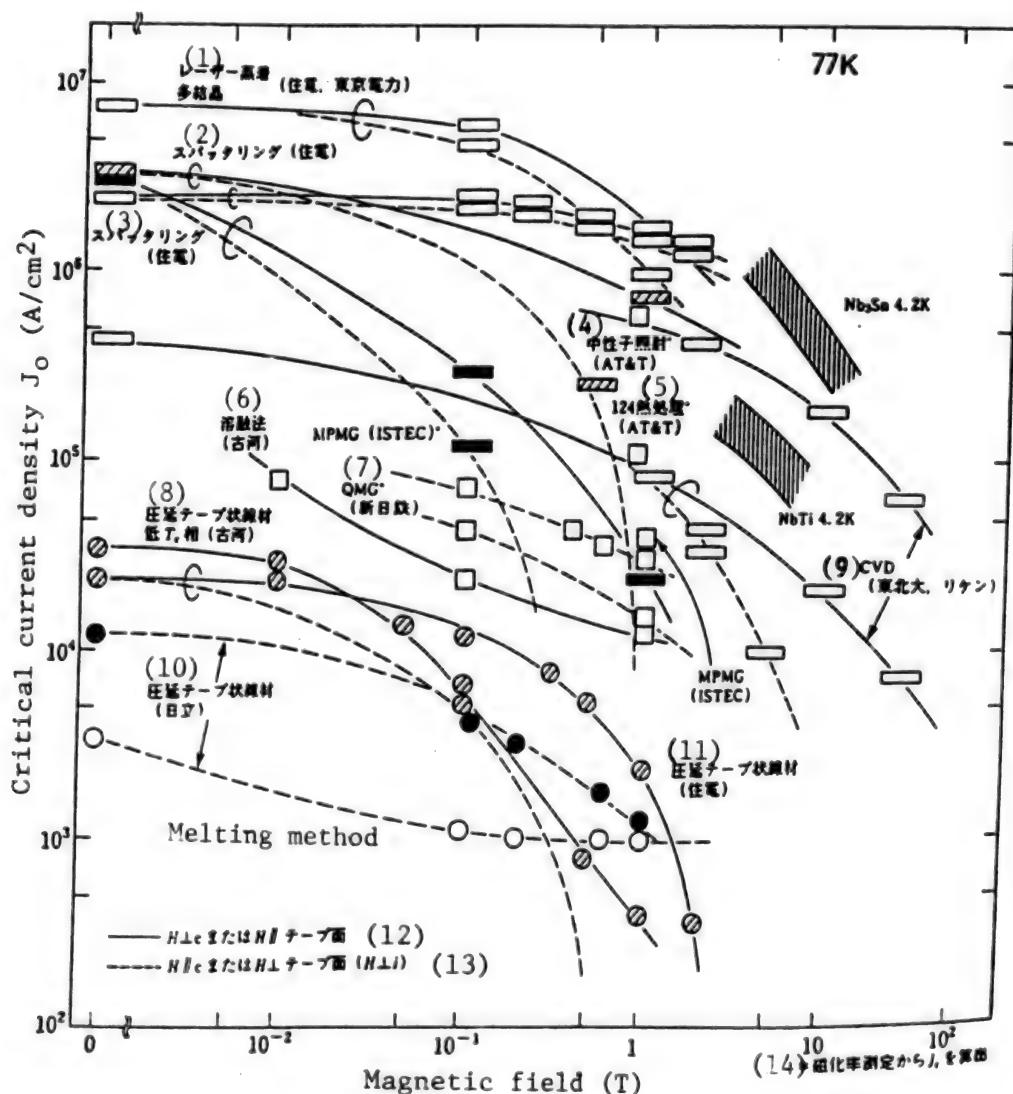


Figure 1. Dependency of Critical Current Upon Magnetic Field (Nikkei Chodendo [superconductivity]: 11 December 1989)

Key:

1. Laser vapor deposited polycrystalline film (Sumitomo Electric and Tokyo Electric Power Co.)
2. Sputtering (Sumitomo Electric)
3. Sputtering (Sumitomo Electric)
4. Neutron irradiation (AT&T)
5. 124 heat treatment (AT&T)
6. Melting method (Furukawa)
7. QMC (Nippon Steel)
8. Rolled tape type wire stock, lower  $T_c$  phase (Furukawa)
9. CVD (Tohoku Univ., Riken)
10. Rolled tape type wire stock (Hitachi)
11. Rolled tape type wire stock (Sumitomo)
12.  $H \perp c$  または  $H \parallel$  テープ面 ( $H \perp c$ )
13.  $H \parallel c$  または  $H \perp$  テープ面 ( $H \perp c$ )
14.  $\rightarrow$  細化率測定から  $J_c$  を算出

9. CVD (Tohoku Univ. and Riken)
10. Rolled tape type wire stock (Hitachi)
11. Rolled tape type wire stock (Sumitomo Electric)
12. Surface with H normal to c or H parallel to the tape surface
13. Surface parallel to c or H normal to the tape surface (H normal to i)
14.  $J_0$  was determined from the measured magnetic susceptibility

The largest obstacle to this realization is the decay of the critical current due to weak bonding at the grain boundaries of polycrystalline materials. Due to its short coherent length, superconductivity is drastically decreased at the grain boundaries, for which there have been no countermeasures found at present. The best way to approach this problem at present is to make the crystal grains long and thin lined up in parallel so that the electrical current does not have to cross the grain boundaries. This highly oriented material shows excellent characteristics. One can say that there are two possible approaches. The first approach is to study the fundamentals of grain boundaries so that measures can be taken to address the problem, a time consuming process. Another approach is to develop a revolutionary manufacturing process to obtain practical wire having approximately the single crystal characteristics along its length. The latter requires a highly advanced and precise manufacturing process technology.

In order to be practical, the wire must be continuous for as long as 1 km. Since technology has made the impossible into the possible in the past, there is no theoretical reason that the things accomplished for 10 cm specimens cannot be processed into 1 km wires.

Another factor complicating the problem is the introduction of pinning centers pertaining to fixing the magnetic flux lines that enter the superconductor. Consistent with its coherent length, the microscopic precipitation of the size of a few ten Angstroms should be scattered throughout the high temperature superconducting material with a separation distance of approximately a few hundred Angstroms. This condition is unintentionally realized in some thin films. The microscopic precipitation of excess copper oxides as the externally caused layer defects are found by the transmission type electron microscope. It has also been found that the creation of artificial defects by neutron irradiation also improves the performance hinting at a technical direction to follow.

### 3.3 Application in Electronics

The basic requirement for device technology is to produce thin films having smooth surface, controlled orientations, and high quality. At present, a variety of means has been explored to produce reasonably good films, although this thin film technology is far inferior to that developed for silicon. There is a mountain of tasks to be addressed with respect to the types and improvements of substrates as well as the re-evaluation of current film forming technologies. In order to solve the heterogeneity problem, I believe that the film should be so formed that its orientation and the layer direction should be normal to the substrate.

SQUID has proven that it is theoretically possible to obtain electrocardiographic measurements at 77K. The future task is to produce a practical and simple system to implement this theory in the device level. Currently it appears that the use of the Tl system having high  $T_c$  is advantageous from the standpoint of reducing noise. In order to make it practical, however, several system-based innovations are needed in the areas of forming reproducible Josephson junctions, production of multi-layer structures, the reduction of hysteresis losses, user convenience, scale reduction, etc. When the simple and easy to use 77K SQUID system is completed, it is expected to open up unexpected markets in the area of sporting facilities.

One cannot help but saying that the development of super high speed devices, essential to electronic applications, appears to be a long way off from the standpoint of difficulties involved in designing and processing superconductive chips. Nevertheless, we must proceed with its basic research to be ready for the day when semiconductor device technology begins to see its limitations. In the Josephson junction, the low temperature superconductivity technology around Nb will be preferred, at least for the time being. Although this technology must be nurtured, the unique and application specific development of high temperature superconductive devices, such as the development of three terminal chips, etc., will be explored.

#### 4. Summary

Superconductivity possesses many attributes suitable for the next generation technology, such that it is clean, energy efficient, super high speed, super temperature sensitive, high accuracy (voltage), etc. Although there exist numerous technological difficulties ahead as mentioned above, it is necessary for Japan to tackle these problems with the long range vision in order to meet the technological challenges of the 21st century.

#### References

For technical information on superconductivity, the annual reports published by the International Superconductivity Research Center, and that by the Multi-Core Project of the Science and Technology Agency are useful as well as the "Nikkei Chodendo" published bi-weekly by the Nikkei BP Company are useful.

As far as the latest articles on superconductivity are concerned, the magazine called "Ouyo Butsuri May 1990" has a special edition on this subject.

For the electron structure and superconductive mechanism, the magazine called "Battery" by Maruzen has a timely discussion on the subject.

Expectation for Space Planes and Thermal Insulation, Thermal Resistance

90FE0316C Tokyo Science Council of Japan in Japanese 27 Apr 90 pp 17-26

[Article by Shigeo Kobayashi, Tokyo Metropolitan University of Science and Technology]

[Text] 1. Current Status of Space Planes and Future Plans

The only space planes which have already completed their flights at present are the U.S. Space Shuttle (the flight in 1981) and the USSR Space Shuttle (Buran, the first flight in 1988). ESA (European Space Association) is currently developing HERMES as part of its Columbus Plan. Japan has also been preparing the development of HOPE. These are the winged flying bodies mounted atop the Alien V and H2 rockets respectively. The gross weight including all equipment aboard will be approximately 17 tons and 10 tons respectively for these ESA and Japanese space planes. While HERMES is designed for a manned flight, HOPE is designed for an unmanned mission. The Alien V and H2 rockets have been developed for their first lift-off in 1996 and 1993 respectively.

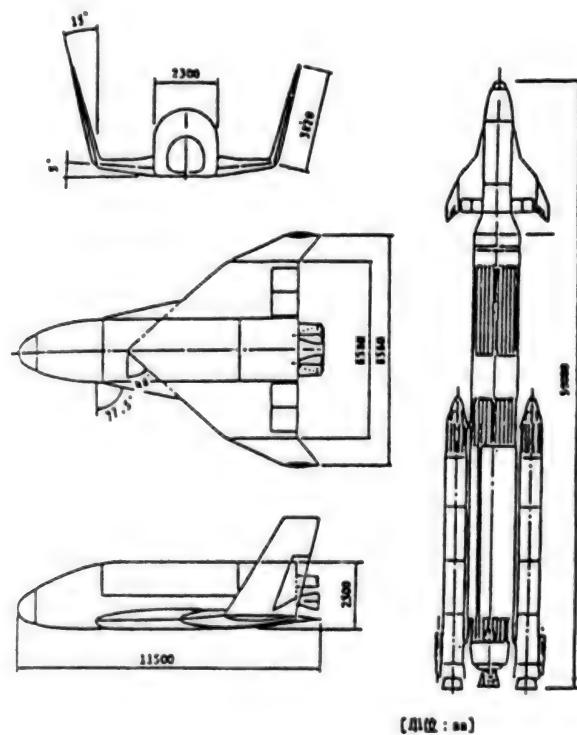
In order to materialize the manned space plane of the 21st century, which can perform the horizontal takeoff, the USA has been conducting research on the components and systems for the experimental plane X30 as a preliminary step. Similar undertakings aimed at the space plane have been going on in the UK on HOTOL, in Germany on SANGER and in Japan on SSTO.

2. Thermal Insulation and Heat Resistant Materials for HOPE

Figure 1 depicts the present planning diagram and the major components for HOPE for its system R&D. The major mission of HOPE is material transport for the space station "Freedom."

Figure 2 shows the computer simulated temperature distribution of the body surface due to aerodynamic friction at the time of reentry. The heat resistant structure can be obtained by three methods: 1) the Hot Structure (the primary structural element exposed to high temperature), 2) the thermal insulation structure (the reduction of the temperature of the primary structural elements by surface insulation), and 3) the forced cooling system. HOPE will not use 3). Its nose cone and the frontal edge of the wings will

be made of a Hot Structure consisting of carbon/carbon composite material. The other parts of HOPE body will consist of insulated structure. In order to reduce the thermal insulation weight, the allowable temperature of the primary structural elements must be raised. If this is done, however, insulation is needed even within the body. Figure 3 depicts a result of the study showing the gross weight change with respect to the choice of primary structural elements.



Principal Dimensions of HOPE

Items	Dimensions
Overall length	11.5 m
Overall width	8.58 m
Overall height	4.4 m
Body width	2.3 m
Main wing area	30 m <sup>2</sup>
Equipped weight	Takeoff time: 10.0 tons Landing time: 7.5 tons
Empty weight	6.5 tons
Payload	Takeoff time: 1.4 ton Landing time: 1.0 ton
Wing loading at landing	250 kg/m <sup>2</sup>
Space stay time	Approximately 4 days
Cross range performance	Approximately 1,000-1,500 km
Landing performance	Automatic landing over a landing strip of 3,000 m

Figure 1. Overall Profile of HOPE and Principal Dimensions

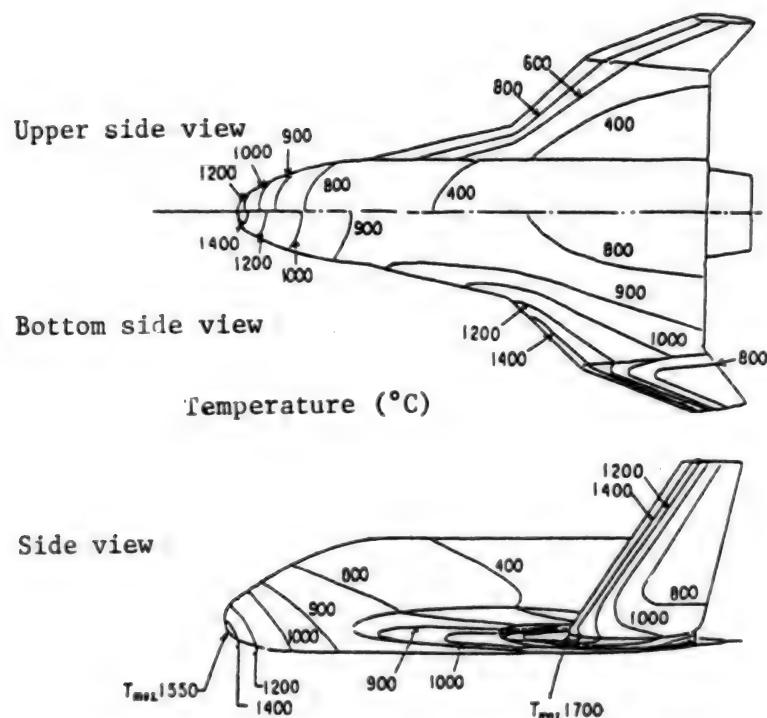


Figure 2. Distribution of Maximum Temperature

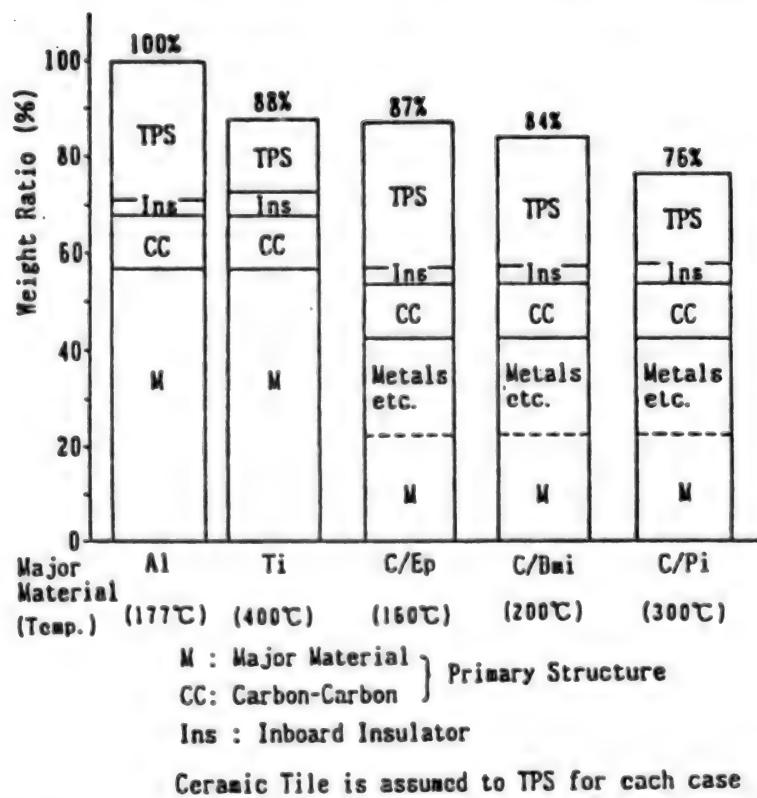
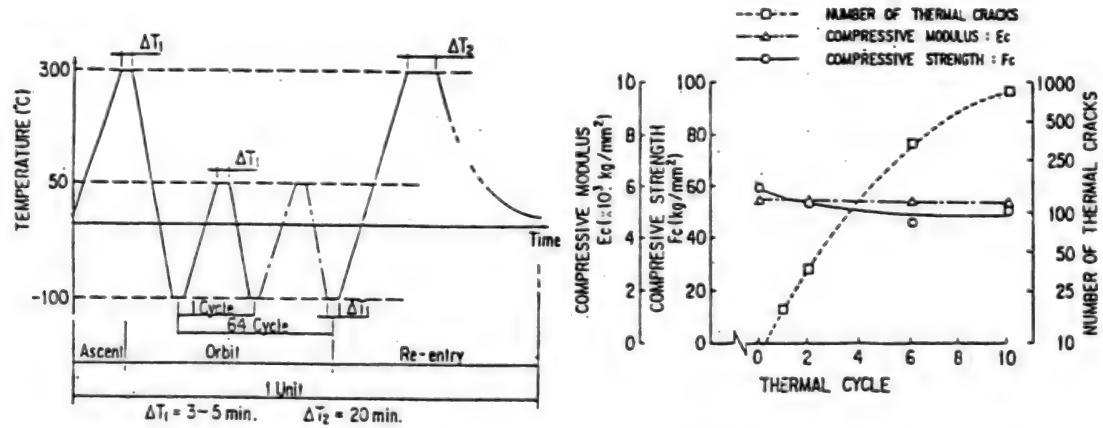


Figure 3. Relationship Between the Gross Weight and Materials Used for Major Structural Elements

As a primary structural element, the most promising is C/Pi (Graphite Polyimid) as far as the weight is concerned. This material, however, produced cracks under thermal cyclic tests as shown in Figure 4. In order to reduce the occurrences of cracks, several measures are reported, such as the elevation of the lower temperature of the thermal cycle and the placement of a mat over the surface layer. Another difficulty of this material is the reduction of its compressive strength under moisture absorbing and high temperature conditions.



(a) Loading profile of thermal cyclic test  
10 unit loading

(b) Changes in strength and stiffness with respect to the number of cracks formed during the thermal cycle test

Figure 4. Thermal Cyclic Test

Table 1 depicts the characteristics of TPS (Thermal Protection System) which had been tested for HOPE. Figure 5 shows two proposed plans for the application of TPS suitable for the temperature distribution depicted in Figure 2.

Figure 6 shows the conceptual design of C/C thermal protection material. In this scheme the C/C composite is used on the surface of a heat resistant panel under high temperatures using an alumina fiber with high density. Light weight silica fibers are used at lower temperatures on the main structure site. C/C composite mechanical properties are shown in Table 2.

Figure 7 shows a conceptual scheme for the use of ceramic tile thermal insulation. In this scheme, the system is so constructed that a medium density product comprised mainly of silicate fibers and alumina fibers, and the low density thermal insulation which is obtained by adding alumino-borosilicate to the medium density product are attached to the body by metallic fasteners through shock absorbing material. One example of ceramic tile characteristics is shown in Table 3.

Table 1. Characteristics of Various Thermal Protection Materials

Thermal protection materials	Composition	Application temperature (°C)	Density (g/cm)	Weight per unit area (kg/m <sup>2</sup> )	Thermal conductivity (at 0.01 ata) (kcal/mh°C)	Thermal expansion coefficient (1/°C)
Ceramic tile thermal protection material	Silica fibers	Less than 1200	0.23	--	0.034 (RT) 0.095 (1000°C)	1.88 x 10 <sup>-6</sup>
	Alumina fibers	Less than 1200	0.12	9.8 (1200°C)	0.026 (RT) 0.138 (1000°C)	3.23 x 10 <sup>-6</sup>
Flexible thermal insulation	Silica fibers + quartz fiber etc.	Less than 650	0.1-0.2	--	0.034 (500°C) 0.086 (1000°C)	--
Titanium alloy thermal protection material	Ti multi-layer panel	Less than 550	--	4.9 (549°C)	0.15 (550°C) (1.0 ata)	Ti alloy material 10. x 10 <sup>-6</sup> (500°C)
Ni alloy thermal protection material	Honeycomb + heat resistant inorganic fibers	Less than 1000	--	9.2 (1000°C)	0.13 (1000°C)	Honeycomb panel 16.3 x 10 <sup>-6</sup> (1000°C)
C/C thermal protection material	Carbon fibers (panel) + heat resistant inorganic fibers	Less than 1300	--	13.0 (1300°C)	0.13 (1000°C)	C/C panel ≤ 0.0 x 10 <sup>-6</sup>

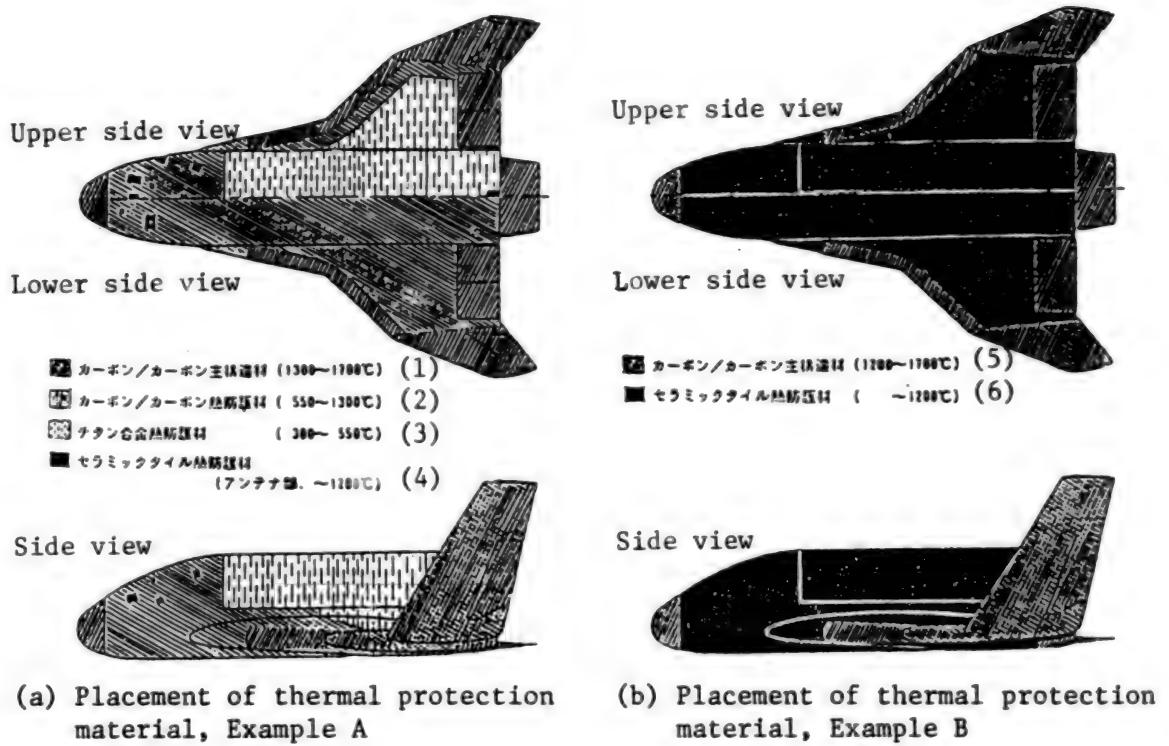


Figure 5. Placement of Thermal Protection Materials

Key:

1. Principal structural material; carbon/carbon (1300-1700°C)
2. Thermal protection material; carbon/carbon (550-1300°C)
3. Thermal protection material; titanium alloy (300-550°C)
4. Thermal protection material; ceramic tiles (antenna section, -1200°C)
5. Principal structural material; carbon/carbon (1200-1700°C)
6. Thermal protection material; ceramic tiles (-1200°C)

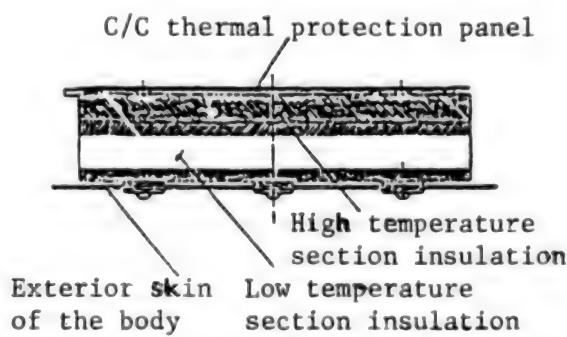


Figure 6. Schematic of C/C Thermal Protection Material

Table 2. Mechanical Properties of C/C Composite Material

Items	Target values	Prototype of this company
Tensile strength (kg/mm <sup>2</sup> )	30	(Under investigation)
Young's modulus (kg/mm <sup>2</sup> )	13,000	(Under investigation)
Bending strength (kg/mm <sup>2</sup> )	25	33.4
Bending elastic constant	8,000	23,500
Interfacial shearing strength (kg/mm <sup>2</sup> )	--	1.59
Temperature resistance (°C)	1,300	1,300
Density (kg/cm <sup>3</sup> )	--	1.9

The target values are NASDA's proposed values

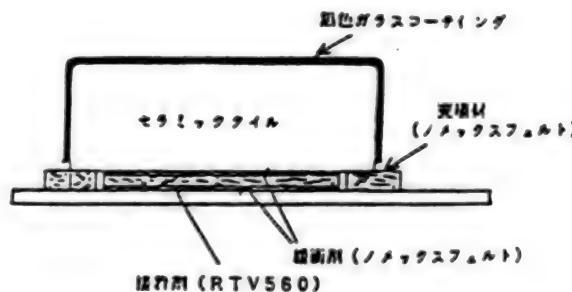


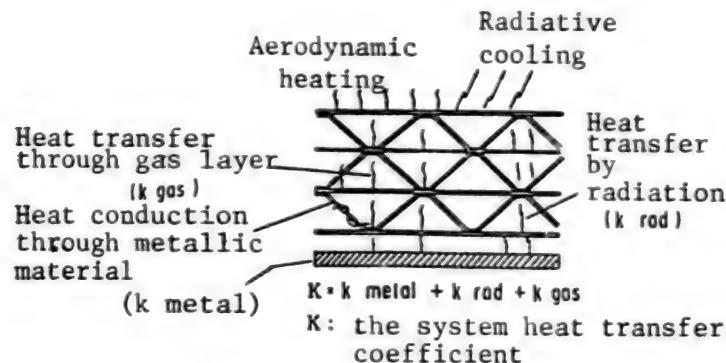
Figure 7. Schematic of Ceramic Tile Thermal Protection Material

Table 3. Major Characteristics of Ceramic Tiles

Items	Medium density material		Low density material	
	Prototype value	Target value (*)	Prototype value	Target value (*)
Density (g/cm <sup>3</sup> )	0.2	0.20-0.25	0.12	0.10-0.15
Thermal conductivity (kcal/mh°C) (at 0.01 ata, 1000°C)	0.095	Max. 0.086	0.136	Max. 0.086
Thermal expansion coefficient (1/°C) (Average)	$1.88 \times 10^{-6}$	$0.5-2.5 \times 10^{-6}$	$3.23 \times 10^{-6}$ [ $2.6 \times 10^{-6}$ ]	Max. $5 \times 10^{-6}$
Tensile strength (kg/mm <sup>2</sup> ) (Along the surface (RT))	21.2	4.9-30	4.7	= 5
(Along the thickness) (RT)	3.72	2.6-3.5	1.54 [2.2]	Min. 1.0
Bending strength (kg/mm <sup>2</sup> )	--	--	8.7	--
Dielectric constant, g	--	--	1.1-1.2	1.2
Dielectric loss, tan δ	--	--	0.006	0.0016

Values in [ ] are the target values for improvement per one FY  
(\*) Temporary target value using the Space Shuttle data

Figure 8 shows the details of the multi-wall type thermal protection structure using titanium alloy foils.



(a) Conceptual thermal insulation

Overall dimensions (mm)		305 x 305 x 18
Dimples	Height (mm)	4.56
	Pitch (mm)	20
Thickness ( $\mu\text{m}$ )	Face sheet	100
	Flat sheet	60*
	Dimpled sheet	100
Material	Ti-6Al-4V	
Specific weight ( $\text{kg}/\text{m}^2$ )	3.6	

(\* the material is Ti-3Al-2.5V)

(b) Conceptual prototype

Figure 8. Titanium Multi-Wall Type Thermal Protection Material

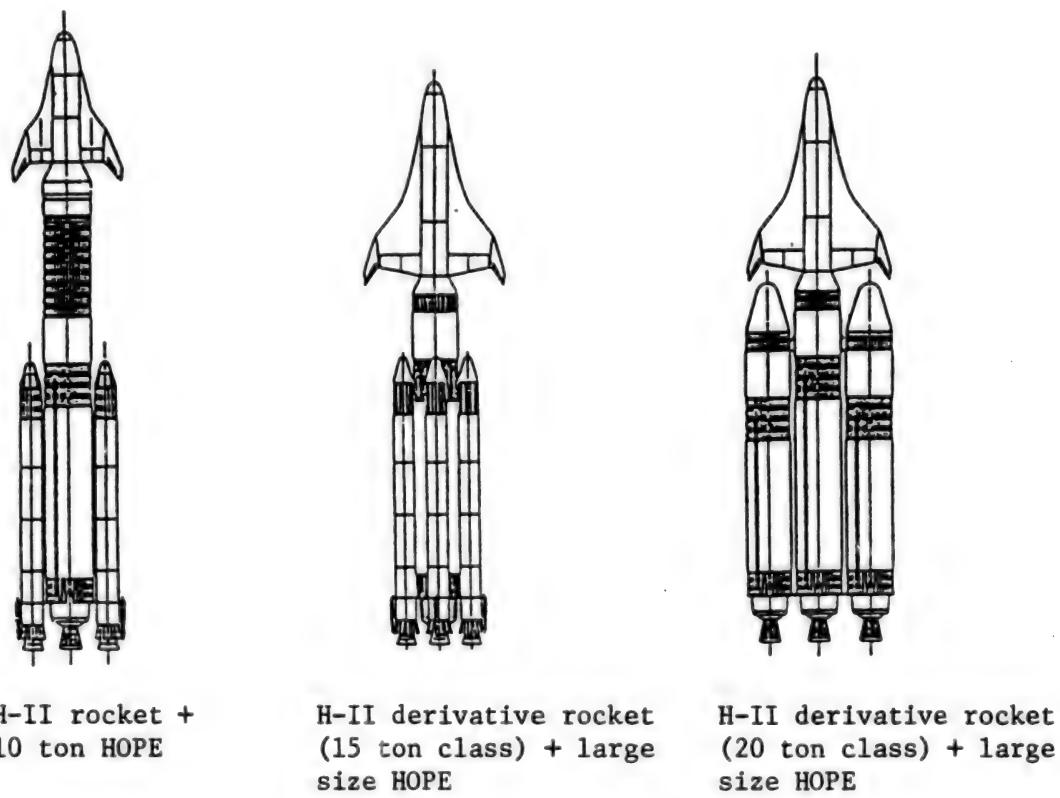
As far as the design of HOPE is concerned, the current thinking is not to use the H2 rocket, but rather to use one of its modified versions, which are shown in Figure 9.

### 3. Expectation of Space Plane and Its Heat Resistant Materials

Figure 10 shows a conceptual picture of the Japanese single stage space plane as conceived at present. This horizontal takeoff space plane utilizes oxygen in the air during its climb, and flies with the speed of Mach 2. Since it is exposed to a long heating period, the high temperature condition is more severe during the climbing period than the reentry period. Figure 11 shows a sample result of the calculated temperature distribution over the body surface during this period.

This type of space plane requires, as its key technology, the development of a compound high performance engine that must be accelerated from a low speed to a high speed in the air and the rocket engine used in the airless space. The next technology needed is to elevate as high as possible the critical utilization temperature of the materials used in the principal structural

elements. The latter requirement is to reduce the body weight. It is also necessary, from the standpoint of improving the engine performance, to develop heat resistant materials for the engine. Table 4 and Figure 12 show the target values for the heat resistant material development shown in the Space Plane R&D Study Report prepared by the Japan Aerospace Industry Association.



H-II rocket +  
10 ton HOPE

H-II derivative rocket  
(15 ton class) + large  
size HOPE

H-II derivative rocket  
(20 ton class) + large  
size HOPE

Figure 9. Concepts of Large-Scale HOPE/H2 Derivative Rockets

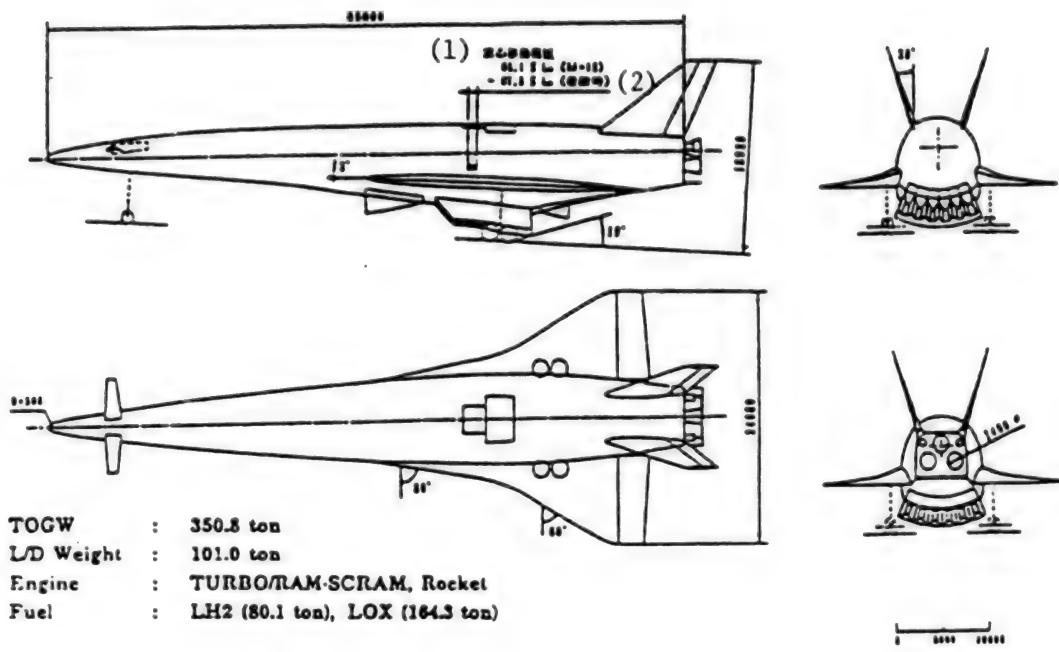


Figure 10. Concept of Single Stage Space Plane

**Key:**

1. Region of the center of gravity variation
2. Takeoff time

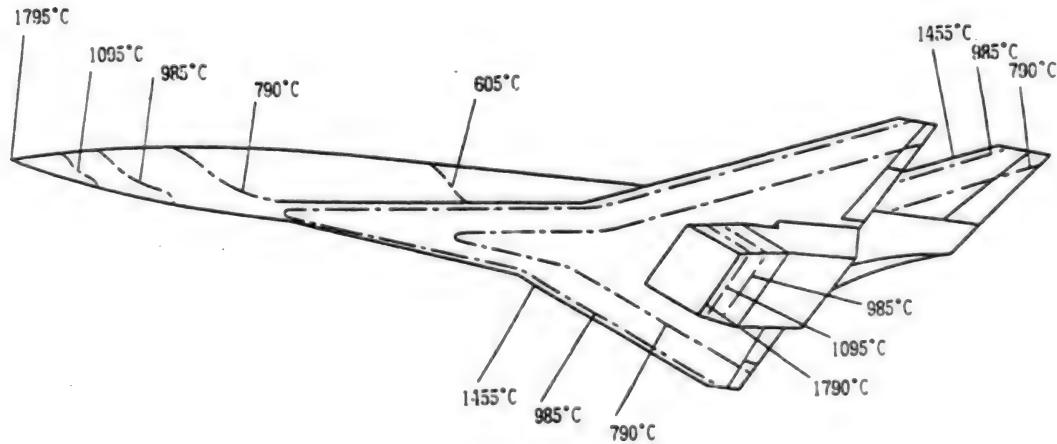


Figure 11. Body Surface Temperature of the Space Plane (M = 6, H = 20 km)

Table 4. Developmental Targets for Space Plane Materials

Structural element	Material classification	Material	Developmental target	
Heat resistant structure (body and engine)	PMC	C Fibers Heat resistant resin	Medium range	<ul style="list-style-type: none"> <li>Strength holding factor:<sup>1</sup> over 90% at 625K (325°C)</li> <li>Durability<sup>2</sup> (1,000 h exposure)</li> </ul>
			Long range	<ul style="list-style-type: none"> <li>Strength holding factor: over 90% at 725K (452°C)</li> <li>Durability (1,000 h exposure)</li> </ul>
	MMC	Ceramic Fibers Al-RSP Ti-RSP	Medium range	<ul style="list-style-type: none"> <li>Application temperature:<sup>3</sup> -900K (627°C)</li> <li>Relative strength: 30 km/900K</li> </ul>
		Ceramic Fibers Heat resistant IMC Super alloy	Long range	<ul style="list-style-type: none"> <li>Application temperature: 900-1500K (627-1227°C)</li> <li>Relative strength: 25 km/1300K</li> <li>Relative creep strength:<sup>4</sup> 3.5 km/1500K, 100 h</li> </ul>
	C/C	Advanced C/C	Medium range	<ul style="list-style-type: none"> <li>Oxidation resistance 2050K (1777°C)</li> <li>Relative strength 25 km (2D)/2050K; 15 km (3D)/2050K</li> </ul>
			Long range	<ul style="list-style-type: none"> <li>Oxidation resistance 2300K (2027°C)</li> <li>Relative strength 35 km (2D)/2300K; 20 km (3D)/2300K</li> </ul>
	Ceramics CMC	Monolithic ceramics	Medium range	<p>Silicon Carbide System</p> <ul style="list-style-type: none"> <li>Temperature resistance: 2000K (1727°C)</li> <li>Fracture strength: <math>8 \text{ MPa} \cdot \text{m}^{\frac{1}{2}}</math>/2000K</li> <li>Relative bending strength<sup>5</sup> 40 km/2000K</li> </ul> <p>Silicon Nitrite System</p> <ul style="list-style-type: none"> <li>Temperature resistance: 1800K (1527°C)</li> <li>Fracture strength: <math>10 \text{ MPa} \cdot \text{m}^{\frac{1}{2}}</math>/1800K</li> <li>Relative bending strength 60 km/1800K</li> </ul>
			Long range	<ul style="list-style-type: none"> <li>Temperature resistance: 2200K (1927°C)</li> <li>Fracture strength: <math>8 \text{ MPa} \cdot \text{m}^{\frac{1}{2}}</math>/2200K</li> <li>Relative bending strength 40 km/2200K</li> </ul>

[Continued on following page]

Structural element	Material classification	Material	Developmental target	
Heat resistant structure (body and engine)	CMC	CMC	Medium range	<ul style="list-style-type: none"> <li>Temperature resistance: 1800K (1527°C)</li> <li>Fracture strength: <math>20 \text{ MPa} \cdot \text{m}^{\frac{1}{2}}</math>/1600K</li> <li>Relative bending strength 40 km/1600K</li> </ul>
			Long range	<ul style="list-style-type: none"> <li>Temperature resistance: 1900K (1627°C)</li> <li>Fracture strength: <math>30 \text{ MPa} \cdot \text{m}^{\frac{1}{2}}</math>/1900K</li> <li>Relative bending strength 60 km/1700K</li> </ul>
	Alloys IMC	RSP-Ti alloy IMC (Ti-Al system)	Medium range	<p>RSP-Ti</p> <ul style="list-style-type: none"> <li>Temperature resistance: 900K (627°C)</li> <li>Relative strength: 15 km/900K</li> </ul> <p>IMC (Ti-Al)</p> <ul style="list-style-type: none"> <li>Temperature resistance: 1150K (877°C)</li> <li>Relative creep rupture strength 5 km/1150K, 100 h (877°C)</li> </ul>
		IMC Ti/Al system Ni/Al system and others	Long range	<ul style="list-style-type: none"> <li>Temperature resistance: 1250-1500K (977-1227°C)</li> <li>Relative creep rupture strength 6.5 km/1150K, 100 h (877°C)</li> <li>Improvement of ductility and toughness</li> </ul>
	FGM	Ceramics/ Ceramics System Ceramics/Metal System	Long range	<p>Thickness: 1-10 mm</p> <p>Surface temperature: 2000K</p> <p>Temperature gap: 1000K</p>

(Notes)

1. Strength holding factor: The ratio of the tensile strength at a designated temperature and that at the ambient temperature.
2. Durability: Exposure resistance capability of retaining the tensile strength above a specified value as determined by the ratio (the strength holding factor) and that under the ambient temperature when the subject material is exposed to a high temperature condition for a specified time (in this case 1,000 hours).
3. Temperature resistance: Generally it is defined as the temperature at which the test material specimen undergoes a creep fracture under a stress expressed in terms of  $00 \text{ kgf/mm}^2$ ,  $\Delta\Delta\Delta\text{hr}$  (for the heat resistant alloys,  $14 \text{ kgf/mm}^2$ , 1,000 hr is often used). In this particular case, it is defined as the temperature under which the material can withstand. The stress condition is to be specified separately.

4. Relative creep fracture strength: Creep fracture strength divided by density (a strength expression for the creep fracture strength ratio).
5. Relative bending strength: Although traditionally we should be dealing with the relative tensile (compression) strength, the relative bending strength is used herein for the convenience of experimental technology.

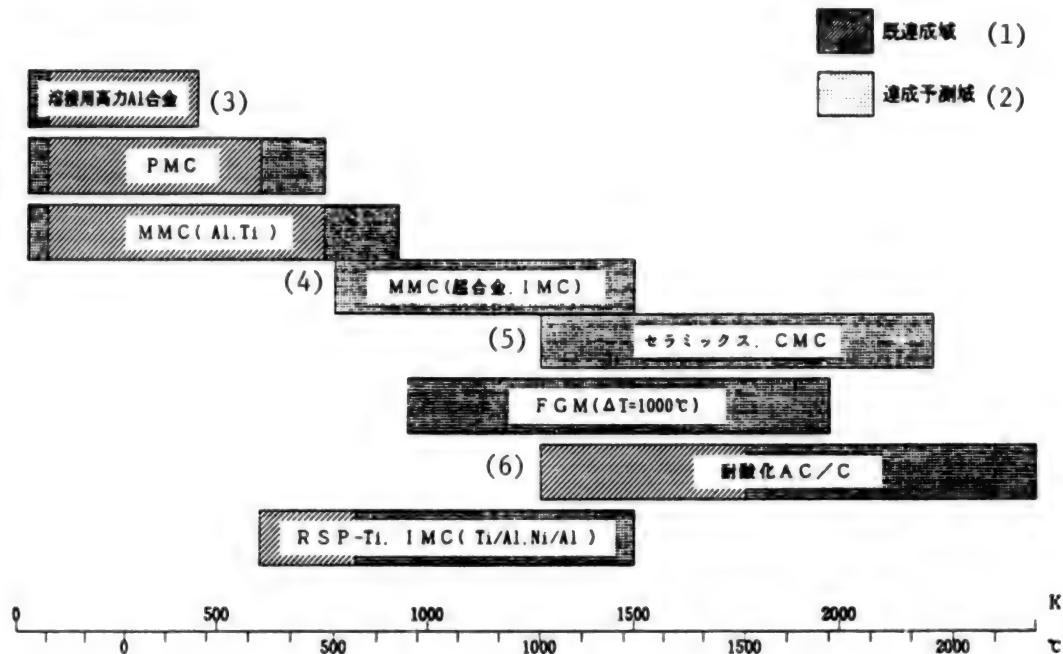


Figure 12. Temperature Resistance of Various Material Systems

Key:

1. The region in which the target has been achieved
2. The region in which the target is anticipated to be reached
3. High strength Al alloy for welding
4. MMC (Super Alloy, IMC)
5. Ceramics, CMC
6. Oxidation proof AC/C

References

1. National Space Development Agency of Japan; Proceedings of the HOPE Workshop, December 1989.
2. Japan Aerospace Industry Association; Space Plane R&D Trend Study Report, March 1990.

## Significance and Impact of Organic Non-Linear Optical Materials

90FE0316D Tokyo Science Council of Japan in Japanese 27 Apr 90 pp 27-34

[Article by Hachiro Nakanishi, Research Institute for Polymers and Textiles]

[Text] 1. Introduction

In order to respond to the information society, which has made rapid advances and which is becoming increasingly multifaceted, the next generation's optical technology is needed to attain the maximum utilization of advantages that light can offer over electricity (such as high speed as well as parallel and space processing capability, etc.). In electronics, various processing functions, such as modulation, amplification, logic arithmetics and memory for electric signal, were realized by creating non-linear responses to an electric signal by means of semiconductors and magnetic elements. In a similar fashion, light technology needs non-linear optical materials which can provide similar functions with respect to laser light as the semiconductors and magnetic elements were with respect to electric signals. Only when this type of material is made available, it is possible for optical devices to process information with higher speed, larger volume and with higher quality than electronic devices. The realization of high performance non-linear optical materials enables the new types of information processing capability such as dynamic holography and various phase conjugation phenomena equivalent to the inversion of time and space, which was not possible by electronic devices. This is the reason that non-linear optical materials are considered to generate a significant impact.

Research on non-linear optical materials has advanced steadily in recent years around inorganic dielectric materials and semiconductors. As the 1980's began, some organic materials were found to possess readily mobile and polarizable  $\pi$  electrons. These organic materials were found to be extremely promising (in terms of the non-linear response, the high threshold fracture strength, the molecule modification, and a variety of material processing methods, etc.). This discovery vitalized research activities on organic type non-linear optical materials in many of the advanced countries. Research activities around the organic materials also stimulated researchers engaged in inorganic materials and semiconductors. It cannot be overstated that the entire research and development activities directed toward the optical technology of the 21st century have been accelerated. With this

background, the Ministry of International Trade and Industry (MITI), to which I belong, has initiated a R&D project entitled "Non-Linear Opto-Electronic Materials" as of FY 1989 under its program for Basic Technology for Future Industry. Discussed below are the current status and tasks in this field centered around polymers.

## 2. What Is Non-Linear Optics?

When light passes through a matter, electrons in the matter (negative charge) will be excited by the oscillating electric field created by light so that its distance from the atomic nucleus (positive charge) will be altered. This will induce a new polarization. The polarization  $P$  induced by light can be expressed by

$$P = X(1) E + X(2) E \cdot E + X(3) E \cdot E \cdot E + \dots + X(n) E^n$$

In this equation, the first term is the linear polarization, the higher terms including the second term are called the non-linear polarization. The constant  $X(n)$  ( $n \geq 2$ ), which serves as the scale for polarization, is called the non-linear susceptibility, and the effect based on the term including  $X(n)$  is called the nth-order non-linear optical effect. The effect due to  $X(2n)$  will be manifested only in materials having asymmetric atomic/molecular structure, whereas the effect due to  $X(2n+1)$  is manifested in the material having symmetric atomic/molecular arrangement as well. Since  $X(2)$  and  $X(3)$  are generally very small, only the linear effect due to the first term  $X(1)$  will be observed when the light intensity  $E$  is weak. For materials having large values of  $X(2)$  and  $X(3)$ , especially when the laser beam is under a large electric field, the higher order terms can no longer be ignored, resulting in the non-linear effect. In other words, the non-linear optical material can be defined as those "showing the second order or higher non-linear polarization responses under the electric field created by the laser beam, and those having various device functions (as shown in the attached figure) due to the non-linear polarization effect."

## 3. Current Status of the Non-Linear Organo-Optic Material Development

The non-linear optical characteristics of organic materials can be expressed by an algebraic summation of molecular characteristics (molecular polarization) including their signs. Consequently, the exploration of various types of molecules (especially the part involving the design and synthesis is called molecular engineering) will be the starting point of the investigation. This will be followed by optimizing the molecular structure in such a way that the characteristics of each molecule can be best utilized (this will be called crystal engineering if it deals with crystals). These are the important steps for material research. The next step is material engineering and system engineering (morphological engineering) to form the material into shapes suitable for the desired output images. During this stage, it is necessary that the device performance be checked concurrently with the material engineering.

### 3.1 The Second Order Non-Linear Optical Effect

When these four steps mentioned above were examined for the second order non-linear optical materials, investigations were made for many  $\pi$  type electron conjugate compounds which possess the electron absorbing group as well as the electron releasing group (including pigments). This was in line with the earlier investigation on 2-methyl-4-nitroaniline (MNA). In addition to the traditional methods of synthesizing new compounds based on checking the existing materials as well as by intuition and experience, the new investigative method using quantum mechanical calculations has recently been actively explored. This is because the non-linear optical response capability of the molecules themselves, namely the molecular polarization, can be expressed as a function of the band gap energy  $E_{eg}$ , between the excited and the base states, the transition efficiency  $\mu_{eg}$ , and the differential polarization  $\Delta\mu_{eg}$  between the excited and the base states. For example, in the irradiation range in which the wavelength scatter and the resonance can be ignored, one can write

$$\alpha = |\mu_{eg}|^2/E_{eg},$$

$$\beta = |\mu_{eg}|^2 \Delta\mu_{eg}/E_{eg}^2,$$

$$\gamma = [|\mu_{eg}|^2 \Delta\mu_{eg}^2 - |\mu_{eg}|^4]/E_{eg}^3 + ?,$$

This shows that the subject compound must have large values of  $\mu_{eg}$ , and  $\Delta\mu_{eg}$  and a small value of  $E_{eg}$ . For the calculation of superpolarization  $\beta$ , several calculation methods were investigated including the simplified method and more accurate methods. It was found, however, that the PPPMO method was able to reproduce the experimental values with sufficient accuracy for the normal  $\pi$  electron system. This accuracy is more than was necessary for the purpose of screening materials. In Japan, this type of calculation has been successfully used for screening molecules for the wavelength conversion. These molecules must have a wide range of transparent regions and a high value of  $\beta$ .

For the crystallization of molecular seeds over the high performance second order materials, or for crystal engineering, there is no royal road, because it is impossible to make the numerical prediction calculation for crystal structures. Thus, the current status is that it must depend on the accumulation of empirical rules for each derivative. The crystal engineering is especially difficult if it aims at a wavelength converter because the asymmetric polarization structure is not the sufficient condition. Further, even for the crystallization taking place in the phase matching space group, the maximum conversion efficiency cannot be achieved in the wavelength conversion for a bulk crystal as long as the molecules do not assume the optimal arrangement specific to each space group. Moreover, when the crystallization takes place with all the molecular vectors aligned in one direction, the phase matching is disadvantageous for the bulk crystal, making it difficult to obtain the high performance material by the powder method screening. Nevertheless, these types of crystals have the large values of coefficient  $d$ , permitting the use of phase matching based on the waveguide

making technique to yield the best high efficiency wave conversion materials for the weak light having the intensity level of that emitted by semiconductor lasers. In the case of p-nitroaniline derivatives which have undergone a thorough investigation ([graphic] (2)), the activity level for the second harmonic generation (SHG) by the powder method, as expressed by a ratio with respect to urea (urea ratio), varies in a wide range from 0-150 depending upon the minute difference in the substitute group. It has been known that NPP is an example of the former while MNA is similar to the latter. In recent years, the material having the urea ratio higher than 1,000 has been found. Although coefficient d is shown in [graphic] (3), the current situation is that a material slightly better than MNA has recently been identified despite the fact that a large amount of investigation has been conducted on this subject. Nevertheless, it is clear from this table that this material is superior to the traditional materials. In an effort to crystallize a cyanic derivative, the authors have shown that the formation of molecular salt is more effective than the introduction of the substitute group. This has been known for its large  $\beta$  value, by the SHG activation. Especially when the use is made of p-toluenesulfonic acid which has a chiral handle capability as a coupled ion for merocyanin molecular salt, the authors found that crystals can be obtained that showed the second example mentioned above. In this case its molecular vectors are perfectly oriented along one direction in the space group P1 ([graphic] (4)). Recently several P1 crystals have been discovered. The future task is then to shorten the wavelength at the end of absorption zone for these crystals. From this standpoint, the LB film is an interesting system in which it is possible to pile up the molecules oriented normal to the substrate in such a manner that the center of symmetry does not exist along that direction. The largest shortcoming of this method is, however, that it shows the optical opacity over some domains, and the important task is to overcome this difficulty. Recently the authors have shown a possibility to produce the second order activated thin film having good optical transparency without using the polling process. This was accomplished by producing a glassy LB film (?) which includes amorphous polymer components and which possesses a polarized structure.

In the process of dispersing transparent polymer molecules in the pigment, a method is available to obtain an asymmetrical arrangement of polymer molecules by an external field such as an electric field. This technique is very interesting for the control of molecular arrangement since it employs the second order morphological engineering technique. In the PMMA-azo pigment system, the coefficient d equivalent of the KDP crystal has been attained. As discussed later, this system has been investigated as an opto-electrical modulation material. The forced arrangement method has a problem because it will be slowed down with respect to time. Nevertheless, the pigment dispersion by the permanent magnetic polymer electrets, the second order activation by the complex formation, a method of which was discovered by Miyata in polycaprolactone-pNA, and the stabilization by the recently investigated bridge are all very promising for future developments.

Table 1. Various Non-Linear Optical Effects and Their Applications

Order	Sensi-tivity factor (Assembly)	Super-polariza-tion factor (Molecules)	Effects	Applications
1	$x(1)$	$\alpha$	Linear dispersion	Optical fiber
2	$x(2)$	$\beta$	Second order harmonic oscillation $(\omega + \omega \rightarrow 2\omega)$ Optical rectification $(\omega - \omega \rightarrow 0)$ Optical mixing $(\omega_1 \pm \omega_2 \rightarrow \omega_3)$ Parametric oscillation $(\omega_p \rightarrow \omega_s + \omega_1)$ Pockels effect $(\omega + 0 \rightarrow \omega)$	Wavelength conversion Generation of DC polarization due to light Variable wavelength conversion (shortening and lengthening of wavelength) Amplification, weak light sensor, variable wavelength change EO modulation
3	$x(3)$	$\gamma$	Third harmonic oscillation $(\omega + \omega + \omega \rightarrow 3\omega)$ DC-SHG $(\omega + \omega + 0 \rightarrow 2\omega)$ The Kerr effect $(\omega + 0 + 0 \rightarrow \omega)$ Optical Kerr effect $(\omega + \omega - \omega \rightarrow \omega)$ Optical mixing $(\omega_1 + \omega_2 + \omega_3 + \omega_4)$	Wavelength conversion, evaluation of sensitivity factor Measurement of molecular super-polarization factor Super high speed light shutter Optical bistability (memory, arithmetic operation), phase conjugation Raman scatter, evaluation of sensitivity factor

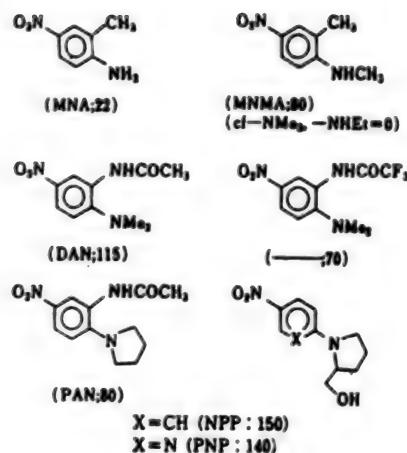


Figure 1. MNA Derivative Showing Strong SHG Activity  
(Urea ratio: powder method)

Table 2. Comparison of the Second Order Non-Linear Optical Coefficients

Compounds	d coefficients (esu)	[r coefficients ( $\text{pm}\cdot\text{V}^{-1}$ )]
$\text{SiO}_2$ KDP $\text{LiNbO}_3$	$d_{11} = 0.80 \times 10^{-9}$ $d_{34} = 1.04 \times 10^{-9}$ $d_{33} = 91 \times d_{11}(\text{SiO}_2)$	$[r_{33} = 30.8]$
Urea m-NA <sup>1)</sup>	$d_{14} = 3.6 \times 10^{-9}$ $d_{31} = 39 \times d_{11}(\text{SiO}_2)$ $d_{33} = 41 \times d_{11}(\text{SiO}_2)$	$[r_{63} = 0.83]$ $[r_{31} = 7.4]$ $[r_{33} = 16.7]$
MNA POM NPP	$d_{11} = 500 \times d_{11}(\text{SiO}_2)$ $d_{14} = 13.5 \times d_{34}(\text{KDP})$ $d_{11} = 164 \times d_{11}(\text{SiO}_2)$ $d_{22} = 61 \times d_{11}(\text{SiO}_2)$	$[r_{11} = 67]$ $[r_{41} = 3.6]$
PMMA + Azo Dye A	$d_{33} = 6.0 \times 10^{-9}$	

1) m-nitroaniline

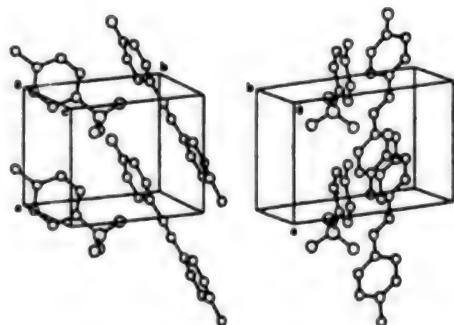
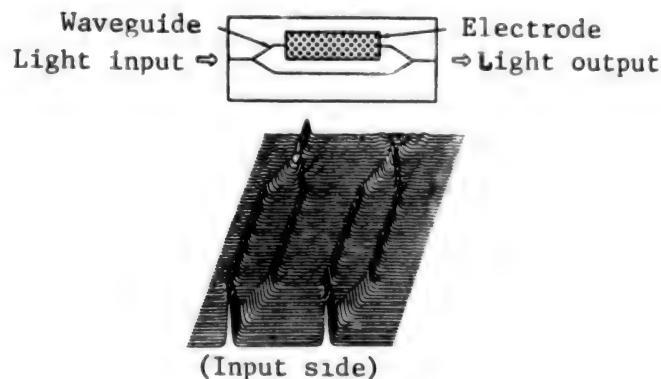


Figure 2. Crystal Structure of merocyanin·p-toluenesulfonic Acid Salt

As to the approach for fabricating devices, much research has been conducted for single crystal growth aimed at wavelength conversion by the bulk material. The m-NA system attained a conversion efficiency of 80 percent under high power input. Recently the conversion efficiency of a few tens of percent has been achieved under the power input of 1 mJ level. The conversion efficiency depends upon the intensity of incident light, coefficient  $d$ , and the optical path length. Since the latter two have the same effect, as long as the crystal growth is easy, the effort to increase the optical path length, by controlling the increase of coefficient  $d$  to some extent, may be a compromise measure for the wavelength conversion of the wide transparent region. As an interesting result, parametric excitation has been found possible for POM, which shows the red, the green and the blue colors generated with a very slight difference in the phase angle. On the other hand, the crystal growth aimed at producing the waveguide is the most promising and practical way of achieving the wavelength conversion in the so-called device level. The advantage of making the waveguide is that it is possible to obtain high density of light wave energy. It also makes the phase matching by the use of mode dispersion characteristics easy, permitting the removal of unusable  $d_{11}$  in the bulk crystal. In the single crystal core fibers, Umegaki et al. have been conducting practical application research which targets the conversion efficiency in the order of a few percent for weak light intensity levels expected by the semiconductor laser. In this research, the important task is to develop an orientation controlled crystal growth technology which arranges the orientation of the molecular spectrum in a desired direction with respect to the direction of the waveguide. Together with this wavelength conversion, the opto-electric effect conversion ([graphic] (5)) also has a possibility of practical application in the near future. In the latter method, there is a polymeric dispersion system which underwent the polling process, and which has the conversion efficiency very close to that of lithium niobate (LN). As far as the frequency characteristics, or the high speed switching, is concerned, this material is definitely better than LN ([graphic] (6)). With the further increase of coefficient  $d$ , the material is very promising in molding into a desired shape and for the practical applications.



The lower left is for non-modulation, while the lower right is for one side modulation with the phase shift of  $180^\circ$  and no light output

Figure 3. Status of Y-Branch Type EO Modulator

Table 3. Comparison of Modulation Performance Between Pigment Dispersion Polymers and LiNbO<sub>3</sub>

	LiNbO <sub>3</sub>		Polymers	
	Normal structure	Special structure	Present status	Target
Switching voltage (V)	3.5	10.5	3.3	0.7
Effective length (mm)	7.5	10.0	27	27
Overall device length (cm)	5	5	5.5	5.5
Driving power requirement (W)	0.6	5.0	0.19	0.008
Maximum switching frequency (GHz)	8	24	No limit (up to the limit of pulse generator)	
Electro-optical constant	31	31	14	70

### 3.2 The Third Order Non-Linear Optical Effect

As compared to the second order effect, whose practicality is very clear, the third order materials have been behind in every respect. First, numerical prediction technology for the material exploration is still a task left for the future. The current status is still the developmental effort centered around the synthesis based on the conjugational polymers. As shown in [graphic] (7),  $X^{(3)}$  is higher than that for the traditional material in the non-resonant region, it is still in the neighborhood of  $10^{-10}$  esu. If the slow response speed is acceptable, it is possible to develop an organic compound having 1 esu for  $X^{(3)}$ . This, however, is not desirable since the objective for the third order device should be the speed. The future task is how to increase the value of  $X^{(3)}$  to the level of  $10^{-7}$  esu ([graphic] (8); cf. [graphic] (9)) which is needed for the device using semiconductor lasers. The authors performed crystal engineering consisting of the design and synthesis of solid phase polymerization to increase the characteristics of polydiacetylene (PDA) which is a stable conjugate polymer in a crystal form. In this process the main complex and the sub-complex are conjugated to increase the number of electrons in a repeated unit ([graphic] (10)). This resulted in the increase of its characteristics to the level at which prototype device experiments using the semiconductor laser are possible. The extension of band gap toward the longer wavelength region, the sharpening of absorption peak, the control of molecular weight and molecular orientation are identified as the important factors for this work. Also started is the research to synthesize origomer. This method has further been applied to the crystals of charge transfer complexes with mobile electrons, pigment dispersion type polymers, and for the polymer dispersion system, and not only the organic molecules, but also to the pseudo molecules (super fine particles of metals and semiconductors having molecule-like properties much more than the conventional particle properties. These can be considered geometrically assembled molecules). In this manner, the application of the method has been widened in the new developmental directions. For this research, the important task for the future will be the investigation of the quantum confinement system which has been suggested by Hanamura.

Table 3. The Third Order Non-Linear Sensitivity Factors for Naturally Activated Polymers

Compounds	Measurement methods	Wavelength ( $\mu\text{m}$ )	$\chi(3) \times 10^{10}$ (esu)	$\tau$ (sec)
PDA-PTS (single crystal)	THG	1.89	8.5(//)	
PDA-PTS (single crystal thin film)	DFWM	0.70	5.0	$<3 \times 10^{-13}$
PDA-ABCMU (orientation controlled vapor deposition film)	THG	1.9	1.8	
PDA-PTS (vapor deposited polycrystalline film)	THG	2.1	cf. 3.8(//), 0.2 ( )	
PDA-BTFP (vapor deposited polycrystalline film)	THG	2.1	0.13	
PDA-PTS (cut thin film crystal)	THG	2.1[1.83]	0.36[7.6]	
PDA-DCHD (cut thin film crystal)	THG	2.1	1.7	
PDA-12,8 (LB film)	SA	0.583	100	$<3 \times 10^{-12}$
PDA-12,8 (LB film)	THG	2.62	0.13	
PBT	THG	1.91	0.5	
PBT	DFWM	0.605	0.09	
Poly(methylphenylsilane)	THG	1.064	0.015	
Poly (di-n-hexyl) silan	THG	1.064	0.13	
Poly (di-n-hexyl) germane	THG	1.064	0.07	
PA	THG	1.064	5.0	
PA	SA (1.17 eV)	300		
Poly C12 Th	DFWM	0.605	4.0	
PPV	THG	1.85	0.078	
PThV	THG	1.85	0.32	
Dalton (ladder) polymer	DFWM	0.532	0.4	
n-Si; p	FWM	10.6(300 K)	3 x 10 <sup>3</sup>	1.0 x 10 <sup>-12</sup>
p-Ge	FWM	10.6(300 K)	1.0	1.0 x 10 <sup>-14</sup>
GaAs/AlGaAs multi-quantum well	DFWM	0.84(300 K)	4 x 10 <sup>4</sup>	2.0 x 10 <sup>-8</sup>
CdS (ultrafine particle)	DFWM	0.532	10-100	

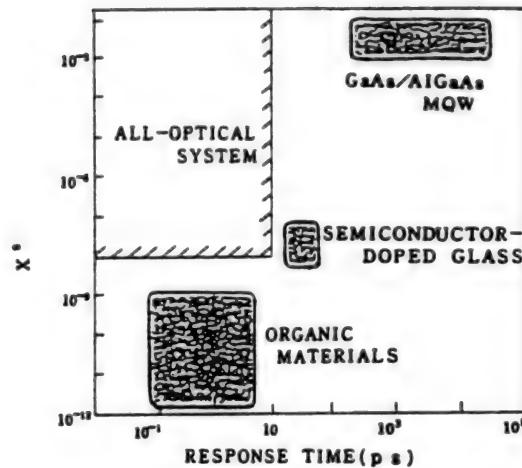


Figure 1. Performance Comparison of Non-Linear Optical Materials. The hatched area indicates target performance

As to the approach to make devices for the third order materials, notable results have been reported on the orientation controlled thin film method using the thin film crystal growth technology and vapor deposition method between two substrates. It has been reported that a four wave mixing experiment using the former technique resulted in the ultra high speed response of less than 1 ps. Following this discovery, the thin film made from soluble PDA verified the ultra fast relaxation time of 30 fs. Also found are the characteristics of the waveguide associative bistable device in the LB film during the process of developing PDA single crystals ([graphic] (9)), amorphous films, and waveguide devices. Although it is centered around the pigment dispersion system, research on the optical car-shutter (phonetics) function and the phase conjugate phenomena are also making steady advance. It is expected that the appearance of high performance materials will expedite the rapid developments in the third order field.



[M.Thakur et al., MRS Symp. Proc. 109, 49 (1988)]

Table 4. Current Status and Future Tasks of Non-Linear Optical Materials

Materials	Current status	Device technology	Future tasks
<ul style="list-style-type: none"> <li>o Material: Mostly pigments, LB films, crystals, polymer dispersion, solution, ...</li> <li>o Material design: The super-polarization factor can be calculated</li> <li>o Performance: Performance in the visible wavelength region is superior to the traditional materials</li> <li>o Crystals: The MNA performance index is over 5 decimals higher than KDP, and over 2 decimals higher than LN</li> <li>o Dispersion films: The EO coefficient is similar to LN, and the frequency response is good</li> <li>o Supply: POM is commercially available. Dispersion films are provided as samples</li> </ul>	<ul style="list-style-type: none"> <li>o Wavelength conversion: R&amp;D stage</li> <li>o Bulk material: Theoretical efficiency under strong light is ~50% under ~mJ light input intensity</li> <li>o Waveguide: a few % level (LD conversion is not available yet)</li> <li>o Parametric excitation and amplification: Verification stage</li> <li>o EO modulation: Similar to LN crystals</li> </ul>	<ul style="list-style-type: none"> <li>o New material investigation: Materials having an enlarged transparent region and higher performance (bulk)</li> <li>o Materials having better performance factor than MNA (waveguide)</li> <li>o Production of new materials and chips:</li> <li>o Crystal growth (larger and lower defects; orientation control)</li> <li>o Basic technology for chip structure</li> <li>o Evaluation and database preparation</li> <li>o New applications: photoref...</li> <li>o New mechanism: ?</li> </ul>	<ul style="list-style-type: none"> <li>o Predictive calculations for molecular arrangement and crystal structure</li> <li>o Exploration of new materials: Establishment of predictive calculation method <math>-10^{-7}</math> esu, <math>-10^{-12}</math> s<math>^2</math> (hetero conjugation)</li> <li>o Quantum confinement; the order effect, size effect...</li> </ul>
Second Order Materials			
Third Order Materials	<ul style="list-style-type: none"> <li>o Current status: Mainly for conjugate polymers; crystals, LB films liquid crystal, films, polymer dispersion, solution</li> <li>o Material design: The super-polarization factor has not been established yet</li> </ul>	<ul style="list-style-type: none"> <li>o Relaxation time: A few tens of fs has been verified</li> <li>o Bistability: Mainly for light-heat effect?</li> <li>o Phase modulation: Design stage</li> <li>o Creation of short pulses: A few tens of fs</li> </ul>	

Materials		Current status	Device technology	Future tasks
o Performance: $\sim 10^{-16}$ esu, $\sim 10^{-14}$ s, $n_2 \pi$ $\sim 10^{-5}$ cm $^2$ /MW cf. Semiconductor MQW $\sim 10^{-2}$ esu, $\sim 10^{-8}$ s " ultrafine particles $\sim 10^{-8}$ esu, $\sim 10^{-11}$ s	o Phase conjugation: Mainly for saturated absorption and for thermal effect	o Mainly for saturated absorption and for thermal effect	o Material and chip preparation: Crystal growth, super lattice preparation o Evaluation and database preparation o New mechanism: ?	

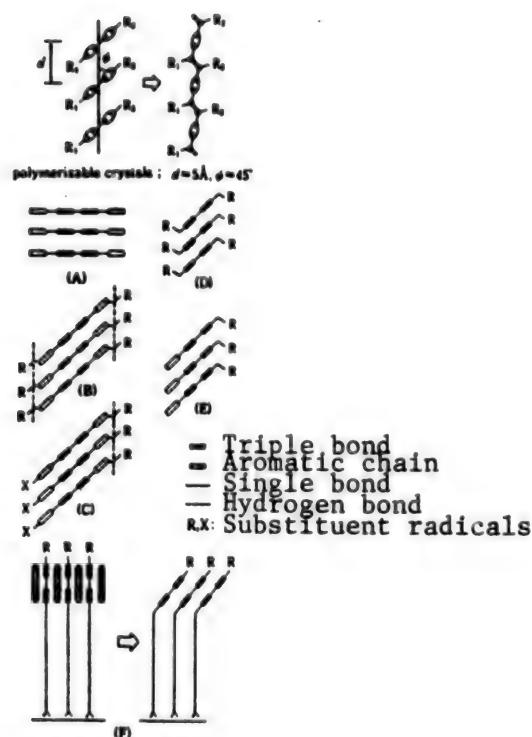


Figure 4. PDA Design Diagram for Main Complex-Subcomplex Conjugation.

When a non-substituent aromatic kernel is bonded to two diacetylene radicals, non-polymerized stack (A) will be formed due to the strong interaction among aromatic complexes. By using the effects due to hydrogen bonding, (B) and (C); the bending effect (E); and by the Anchor-void effect (F), it is, nevertheless, possible to crystallize diacetylene, which is bonded directly to an aromatic ring, into an arrangement having the solid phase polymerization characteristics.

#### References

1. "Nonlinear Optical Properties of Organic and Polymeric Materials," D. J. Williams Ed., ACS Sympoium Series, 233, pp 1~ (1988).
2. "Organic Nonlinear Optical Materials," Kato and Nakankshi Ed., CMC R&D Report No 72, pp 1~ (1985).
3. "Nonlinear Optical Properties of Organic Molecules and Crystals," D. S. C. Chemla and J. Zyss Ed., Academic Press, Vols 1 and 2, pp 1~ (1987).
4. "Nonlinear Optical Properties of Polymers," A. J. Heeger, J. Orenstein and D. R. Ullrich Ed., MRS Symposium Proceedings, 109, pp 1~ (1987).
5. Umegaki, "Zairyō Gijutsu" (Materials Technology), 5(9), (1987).

6. Nakanishi, Okada, and Matsuda, "Kinou Zairyo" (Functional Materials), (6), 5 (1988).
7. Hanamura, O pluse E, 103, 77 (1988).
8. Kobayashi, "Sen'i to Kogyo" (Fibers and Industry), 45(2), p 68 (1989).
9. Nakanishi, "Koubunshi" (Polymers), 38(5), 350(1988).
10. Okazaki et al., "Yuuki Gosei Kagaku" (Organic Synthesis Chemistry), 47(5), 457 (1989).
11. "Organic Nonlinear Optical Materials and Developments in Device Technology," the 36th Joint Conference of Applied Physics Related Societies, Symposium Digest Edition, AP891211-01 (1988).
12. "Hisenkei Kogaku Zairyo" (Nonlinear Optical Materials), Special Edition of Kotai Butsuri (Solid State Physics), 24(11), pp 1~ (1988).

#### The Authors' Research on the Second Order Pigment Complexes

13. Nakanishi, Matsuda, Okada, Kato, and Masaki, 1988 Report of the Research Institute of Polymers and Textiles, p 82 (1988).
14. H. Nakanishi, H. Matsuda, S. Okada, and M. Kato, MRS Int'l. Mtg. on Adv. Mats., Vol 1, 97 (1989).
15. Okada, Masaki, Matsuda, Ueno, and Nakanishi, the 50th Conference of Applied Physics Society, ZP4/III; Nishikawa, Ishikawa, Kokufuda, Okada, Masaki, Matsuda, Nakanishi, and Kato, the same as above ZP5/III (1989).
16. Sakai, Oumi, Koike, Okada, Masaki, Matsuda, Nakanishi, and Umegaki, the 37th Joint Applied Physics Conference, 30aQ3; Koike, Oumi, Sakai, Umegaki, Okada, Masaki, Matsuda, and Nakanishi, the same as above, 30aQ7 (1990).

#### On Polar Structured Glass

17. S. Okada, H. Nakanishi, H. Matsuda, M. Kato, T. Abe, and H. Ito, Thin Solid Films, 178, 313 (1989).

#### On New PDA

18. S. Okada, H. Nakanishi, T. Hosomi, and M. Kato, Macromolecules, 21, 1238 (1988).
19. H. Nakanishi, H. Matsuda, S. Okada, and M. Kato, "Frontiers of Macromolecular Science," Blackwell Sci. Pub., pp 469 (1989).
20. H. Nakanishi, H. Matsuda, S. Okada, and M. Kato, "Nonlinear Optics of Organics and Semiconductors," T. Kobayashi Ed., Springer-Verlag, pp 149 (1989).

21. Osugi, Hourai, Matsuda, Okada, Masaki, and Nakanishi, the 38th Polymer Conference, 3K16 (1989).

On the Pigment Dispersion Systems

22. H. Matsuda, S. Okada, T. Nishiyama, H. Nakanishi, and M. Kato,  
"Nonlinear Optics of Organics and Semiconductors," T. Kobayashi Ed.,  
Springer-Verlag, pp 188 (1989).

23. Toyama, Okada, Matsuda, Masaki, and Nakanishi, the 38th Polymer Conference, 3K11 (1989).

Others

## **Electronics Industry--Life After Its Maturity**

90FE0316E Tokyo Science Council of Japan in Japanese 27 Apr 90 pp 35-41

[Article by Shojiro Asai, Hitachi Manufacturing Co., Central Laboratory]

[Text] 1. Introduction

What we currently consider electronics implies a new technology represented, for instance, by TV's, compact discs, computers, engine control equipment, mobile phones, FAX's, etc. These products have been undergoing rapid improvements providing continuous streams of new conveniences, comforts and stimuli all around us.

When one thinks about current-day electronics, the first thing that strikes him/her is its variety. There is a variety of usages and applications. Although electronics was represented by transistor radios at first, it is now impossible to cover all electronics applications by those mentioned above. Electronics hardware has been increasing its complexity year after year culminating in the VLSI, one of its current and typical hardware, integrating approximately  $10^7$  elements of integrated circuit parts. While the early phase of electronics consisted mostly of hardware, hardware and software are important at least to the same degree in many current electronics products. When one considers the progress in electronics, one must look at it from three standpoints, namely hardware, software and applications. The steel and machine technologies, which made the first generation industrial revolution, have passed their maturity stages showing signs of having reached an ultimate level. How about the electronics industry which supports the second generation industrial revolution?

Like any other industries, electronics will eventually reveal its ultimate state and enter into a decay period following the maturity stage. If that day comes, what shape will electronics assume? How far can the hardware advance? What targets should software aim at? How wide should the application area become? When will this stage occur? This lecture will address these issues.

## 2. The Ultimate of Electronics Hardware = Atomistics

### From LSI to Optical Devices

If narrowly defined, electronics is the hardware technology called the solid state device, which mainly started from transistors and has advanced to the extremely high density integrated circuits called the USLI by going through the VLSI stage. The current devices include light sensitive devices represented by lasers and APD's, as well as optoelectronics including fiber optics and OEIC. If the scope of electronics is expanded, it can even include the magnetic optical memory devices.

### The Trend Is Miniaturization

The trends: One unique feature of electronic hardware is its small size. Generally speaking, the cost per unit volume has remained constant. Moreover, the hardware capability (performance) contained in a given volume has been increasing together with the advance in its technology. The major component of this advance may be represented in the miniaturization of LSI chips and resulting high densification. The degree of LSI integration has quadrupled every 3 years (one generation) over the past 15 years, in which the doubling effect is caused by the miniaturization of device dimensions.

The remaining factor for the miniaturization of LSI integration is attributed to the innovations in circuit design, three dimensional chip structure, and some dimensional growth tolerated in the chip size growth. The chip size increase has, however, been compensated by the innovative packaging technology and the new technology in printed circuit boards so that the increase of the overall system volume has been prevented. The dimensions of the LSI device are, therefore, measures for the advance in electronics hardware. The ultimate dimensions of the device would, therefore, imply one of the factors that determine the ultimate state of electronics technology. There are several factors that limit the infinite miniaturization of device dimensions. They include the physics based limit resulting from the operating principles of the device, the technological limit due to the yields and reliability associated with production technology, and the economic limit from the standpoint of recovering costs involved in investing new production and developmental facilities.

The current investment expenses required for manufacturing semiconductor products in an industrially significant quantity have been doubling every generation of electronics (3 years) and have reached the magnitude of several tens of billions of dollars. Against these expenses, the demands for the new products have been increasing approximately by 1.5 times every 3 years. It has been said that eventually there will be no manufacturers left who will be investing in miniaturization. The total worldwide electronics market in 1990 is \$86 trillion, in which \$7 trillion is for semiconductors. If one assumes an annual growth rate of 15 percent, these figures will be quadrupled in the year 2000. If it is assumed further that investments by semiconductor manufacturers in 1990 is in an order of \$1 trillion, and if the growth rate mentioned above is also accepted, the

necessary investments in the year 2000 will be \$10 trillion, which will be one-third of the predicted sales. In reality, the technological limit described below will increase, which substantiates the prediction that miniaturization beyond a certain level becomes economically impossible.

The year 2000 will be, if one follows the current trends, the age of the ULSI represented by the 256 Mb DRAM's using the device based on a minimum line width of 1/4 micron. It is predicted that the devices of from 0.2 micron to 0.1 micron size will be then under development. The problem encountered at that stage will be the technological limit in developing appropriate manufacturing methods represented by lithography, the increasingly serious yield problems, and reliability problems. In order to secure reliability, the device structure and materials that can mitigate the high electric field effect have to be developed. In order to increase the production yields, the required task is how to introduce the redundancy circuit technology, which has been widely used in the LSI memory, into the logic circuit. Another problem is that the sizes of contaminants and pollutants affecting the yields become the levels of atoms and molecules.

#### The Ultimate Is the Atomistics

In the developments of cutting-edge electronics hardware as described above, the need for technologies to inspect, identify, separate, transport, and store the material in the level of atoms and molecules will be highlighted. The present examples, in which these trends have already started, are the ALE (Atomic Layer Epitaxy), the STM (Scanning Tunneling Microscopy) and the FPB (Focused Particle Beam) technologies. Thin films having a thickness of several atomic layers have already been used in super-lattice structures in the MQW lasers and super-thin films for the DRAM's. There are many cases in which the interfaces of these films and the defects in their p-n junctions control the device performance. There is a need for technology to observe and ultimately to control the structures of these devices. The science to address this field is called "atomistics." Atomistics is an area of investigation leading to the ultimate of electronics, which no one can bypass.

#### Future Electronics

The physical limit for device miniaturization has been said to be around 0.1 micron. If the device is cooled by liquid nitrogen, some say that it can be possible to miniaturize the device down to a 0.025 micron level. When the miniaturization is done in this range, there will be several phenomena, such as the destruction of insulating property of films due to the tunnel effect, and the reverse directional voltage across the p-n junction, or the tunnel destruction. These depend upon the manner in which the device is used in the circuit, the selection of materials, and the manner in which the device is constructed. Judging from the technological limit, I believe that the miniaturization and the densification of integration will be advanced to such a level that the 0.2 micron chips and  $10^9$  elements/chip will be possible. Before this level is reached, however, atomistics will play the role in developing various guidelines and milestones. In addition, there are possibilities that new types of useful

materials can be synthesized and new principles for the device may be discovered from atomistics. It is possible to obtain several feedback possibilities from technology to science. There is a definite need to start research on atomistics for the analyses and applications of solid state phenomenon in order to attain the ultimate miniaturization.

### 3. The Ultimate of Electronics Software = Natural Language Interface and Self-Organization

#### More Than One-Half of Electronics Is Software

Currently, more than 50 percent of electronics technology is made up of software. Except for computers, there are very few cases at present that the software price exceeds the hardware price in the products purchased by the users. Nevertheless, if one includes the software costs involved in the development of hardware, the electronics industry depends on software for more than 50 percent. While the electronics industry advances toward the year 2000 with an anticipated growth rate of 15 percent per year, the software growth rate is anticipated to be 25 percent per year. What will be the ultimate form of software?

#### Higher Leveling and Abstracting

Since the birth of computers, their software has been upgraded constantly with respect to its levels and degree of abstraction. The computer programs which used to be written in the machine language have been upgraded through the various higher level languages, such as the assembly language; FORTRAN; PASCAL which can describe the data structure, the C and finally to the several proposed object oriented languages. Although all of these languages, when they were first introduced, received wide acclaim as being a result of artificial intelligence, presently they all constitute more or less a part of the compilers. One may say that the compiler technology has been pushed by the advance of hardware technology to enable the processing of these various languages for user convenience.

As to the description method (software) for the hardware design, progress has been made in achieving higher levels and higher degrees of abstraction. During the early stage of IC developments, the design was done mainly by leveling up the circuit diagrams before the circuits were transposed to the silicon wafer. The "layout" of the circuit was done manually. Later, the software technology was gradually developed in generating patterns over the silicon wafer surface from the circuit diagram. The abstraction technology has advanced so much now that it is no longer necessary to know anything about the circuit diagram or the silicon patterns. The silicon can be designed simply by providing the LSI function specifications in a high level language. Research and developmental work has been in the realization of the "silicompiler" technology.

Assume an engineer or a scientist is asked to solve a partial differential equation which he or she may not be normally familiar with. Assume, for example, instead of writing a computer program consisting of "If...Then...Else" and/or DO loops, the only thing that the engineer or the scientist

has to do is to describe the differential equation and its boundary conditions. If this can be accomplished, it will be the realization of a high level language close to natural language as far as the world of science goes. One such language is "DEQSOL." In this system, a FORTRAN program is first generated automatically before it is solved by the supercomputer.

#### From How to What

As discussed so far in this paper, the progress in hardware and software has made it no longer too difficult to solve problems in which man has to process information (how). In the present stage, however, man still often has to convey his intent (what) uniquely to computers when he gives instructions. This is sometimes inconvenient. One of the ways to solve this problem is to use natural language as an interface. A sentence understanding capability should be developed to recognize the accurate meanings from natural language sentences by making references to its context, conditions and previous examples, etc. In a similar vein, hardware has already been using input devices such as a pointing device represented by the mouse, light pens, scanners, etc. In the near future, even practical soft- and hardwares that recognize voices and gestures may be developed. Also important is the "self-organization" capability in which appropriate decisions and new ideas can be generated based on the analysis of experiences accumulated in the past. The self-organization capability will be one of the conditions for the ultimate electronics software in which computers and man can interface with each other without any difficulties.

#### Future Electronics Software

In order to achieve the objectives mentioned above, a visual language has been proposed to interface with the computer through the visual senses, and eventually to construct the computer programs using visual examples. Another software structure model beginning to be studied at the present is to place an agent, which is a representative, in the computer to assist the self-organization of the software using negotiation between the user and the agent. Another important task is to conduct software research on the effective operation of parallel computers consisting of a multitude of processors. One difficulty awaiting a good solution in this task is the distribution of one information processing task to many computers depending upon their capabilities.

Grossly speaking, one may say that software is designed to prepare a tool to ease up the idea generation for "what." Since the future trend is the individualization of information processing and usage, various devices will be developed to assist in the breakthroughs in the limits of the individual's capability. For example, (it is difficult to remember the faces of persons whom you meet for the first time), if the computer can recognize the faces, it becomes possible to develop interfaces suitable for specific individuals, to integrate the environmental factors appropriate for those individuals. In this manner, a large-scale task can be accomplished most effectively by integrating the individuals' needs. This concept is called the CSCW (Computer-Supported Cooperative Work) and its research

results can be realized by the face recognition capability. In order to satisfy these requirements, it is necessary to advance research on neuro logic, fuzzy logic and self-organization logic etc. as the bases for information science.

#### 4. The Ultimate of Applications = From Reasons to Senses

In the final analysis, electronics consisting of hardware and software is meaningful only when it is known as to what purpose its products are used, or its applications. Many systems, tools and equipment created by man to satisfy his or her conveniences, pleasures, comforts, etc. for a variety of different purposes, have been made possible for the first time by electronics. Where are these applications heading to?

##### Efficiency Increase, and Tool for the Individual's Objectives

The attainment of small sizes, high speeds, low prices, and higher functions, etc. which has been made possible by electronics, is all for the purpose of meeting societal needs that are constantly seeking higher efficiency. These trends are best represented in the progress in the computer as a tool to support the maximizing of the individual's intellectual activities. In the computer's world, miniaturization has progressed through minicomputers, personal computers, lap-top personal computers, hand-held personal computers, etc. If one looks at this trend from the user's point of view, it has moved from the age when many people shared a large machine to the age when individuals can possess highly developed electronics. At the same time, a large bottleneck exists at the present in the area of communication (including the interchangeability of the data) among the computers used by the individuals. The needs are increasing for long distance data communication, local area networks, etc. In the future, advances will be made on data interchangeability and the portability of the machines, which will permit anyone to work and enjoy in any place he or she so chooses in the same manner. Electronic products will be used in this manner in the future.

##### From Functional Beauty to Superfluous Beauty

As individuals' usage of computers increases, the demands on computers are at a higher level and are more variable, it is no longer sufficient simply to provide necessary functions. This trend is clear not only in the popular electronics products but also in the information machines represented by personal computers. The ultimate application is to recognize the importance of appealing to human senses in addition to human reason. Becoming necessary is the superfluous beauty which is based on esthetics rather than on the functional beauty resulting from satisfying the necessary functions. Even in the field of electronics, this trend is evident in the color displays which have changed from the 16 color system to the 16 billion color system, and in the rapid advances made in the computer graphics (CG). The high speed and the high quality digital/analog converters having 16 bits to 18 bits have been developed to be able to synthesize high quality sounds. This has expedited the research on computer music (CM). The time is coming when

electronics will be playing active roles in the arts, hobbies, and the entertainment area in which the traditional yardsticks for electronics to measure speed and efficiency cannot be applicable. CG and CM will no longer be simply tools, but they will be extended to the CAAD domain (Computer-Aided Artistic Design) to create new art forms in which the computer can be exploited to manipulate space and time. If one can say that the traditional applications were to support the creative activities of the left brain, the applications appealing to the senses will be to assist the activities of the right brain.

In addition, the applications of traditional electronics will be expanded into translation machines, the various medical electronics (MRI, PET, etc.), micro-robotics, environmental measurements, etc. Among these applications, a new technological field called the "esthetic intelligence" will be required, which is to surpass the "artificial intelligence." In order to develop this new technology, it is necessary to advance the technologies in new types of intelligence processing called the qualitative reasoning and the aspect reasoning for establishing a system capable of analyzing sensory stimuli.

##### 5. Summaries

The strength of the Japanese industries during the 1970's and 1980's has been the hardware-based electronics. This hardware-based electronics supported the developments of TV's, VTR's, CD's, laser disks, video cameras, computers and other major equipment. Although the importance of electronics in this area may not diminish in the next 10 years, future electronics demands the revolutionary progress in software in addition to the hardware. It is necessary, therefore, for the advanced research in electronics, consciously to nurture the basic science field that supports the future of the electronics industry. Urgent and effective efforts must be made for the expansion of basic research facilities and equipment, and the training of young researchers and technicians. This can be accomplished not only by depending upon the research and development among all companies, but also by the expansion of national facilities directed toward international contributions. Concrete examples of such undertakings will be the creation of a third sector type research institute operated under federal funding, and the creation of a science foundation to support the basic research themes with the cooperation among industry, universities and the government based on the national budgets. It is hoped that the companies, government, and universities will start new activities beyond the framework in which traditional research has been conducted in the past.

**END OF  
FICHE**

**DATE FILMED**

21 Dec. 1990